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Concentration Technologies for Hazardous Aqueous Waste Treatment

Touhill, Shuckrow and Associates, Inc.
Pittsburgh, PA

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CONCENTRATION TECHNOLOGIES FOR HAZARDOUS AQUEOUS WASTE TREATMENT

by

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Contract No. 68-03-2766

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16. ABSTRACT

A stepwise evaluation of the potential applicability of the candidate technologies to the identified contamination problems was carried out. Technology profiles describing the pertinent processes and current applications were prepared. These profiles formed the basis for the initial screening of the applicability of individual technologies to concentration of hazardous constituents of aqueous wastes. Certain technologies were eliminated from further consideration for reasons discussed in the individual technology profiles. Remaining technologies were carried forward for more detailed review. Compounds identified in the waste streams fell into one of thirteen chemical classes: alcohol, aliphatic, amine, aromatic, halocarbon, metal, miscellaneous, PCB, pesticide, phenol, phthalate, or polynuclear aromatic.

The next step in the evaluation process was an extensive literature review which focused on the technologies and upon chemical compounds classes. It was concluded that six processes: biological treatment, chemical coagulation, carbon adsorption, resin adsorption, membrane processes, and stripping have the greatest potential broad range and immediate applicability.

In most cases, no single unit process would be sufficient in itself to adequately treat the diverse contamination problems likely to be encountered. Five candidate process trains were formulated as being most broadly applicable to the types of known contamination. A desktop analysis then was performed to assess the ability of each process train to treat each of three selected contamination problems.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communication link between the researcher and the user community.

This report is the first in a two-volume series of comprehensive studies dealing with the treatment of hazardous constituents of aqueous waste streams. This report describes an ongoing program to evaluate and verify several technologies for the treatment of waters contaminated by hazardous wastes. The results of an extensive evaluation of 18 concentration technologies are discussed. It was concluded that six processes: biological treatment, chemical coagulation, carbon adsorption, membrane processes, resin adsorption, and stripping have greatest potential broad range and immediate applicability to treatment of hazardous leachates and contaminated groundwater having diverse compositions. Capabilities of each of these six technologies are discussed.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This report describes an ongoing program to evaluate and verify several selected concentration techniques for hazardous constitutents of aqueous waste streams. In the first phase of the project, data was obtained regarding the performance of unit processes for concentrating the hazardous constituents. Applications are expected in the treatment of ground and surface waters affected by the disposal of hazardous wastes.

In conjunction with gathering data on the unit processes, data were obtained on the composition of the waste streams to which the processes could be applied.

The second phase involved a stepwise evaluation of the potential applicability of the candidate technologies to the types of wastes identified earlier. Technology profiles describing the pertinent unit processes and current applications were prepared. These technology profiles formed the basis for an initial screening of the applicability of individual technologies to concentration of hazardous constituents of aqueous wastes. At this point, certain technologies were eliminated from further consideration for reasons discussed in the individual technology profiles. Remaining technologies were carried forward for more detailed review. Compounds identified in the waste streams fell into one of thirteen chemical classes: alcohol, aliphatic, amine, aromatic, halocarbon, metal, miscellaneous, PCB, pesticide, phenol, phthalate, or polynuclear aromatic.

The next step in the evaluation process was an extensive literature review which focused on the technologies which survived the initial screening and upon chemical compounds in the classes given above.

Since it was evident that in most cases no single unit process would be sufficient in itself to adequately treat the diverse waste streams in question, five candidate process trains were formulated as being most broadly applicable to the types of waste streams identified. A desktop analysis then was performed to assess the ability of each process train to treat each of three waste streams. Results of these evaluations provide a basis for making an initial judgment on the applicability of a given concentration technology to specific situations in the absence of experimental data. Results also were used to select

ABSTRACT (continued)

and arrange technologies in priority order for experimental study in the ongoing third phase.

This report was submitted in partial fulfillment of Contract No. 68-03-2766 by Touhill, Shuckrow and Associates, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period March 1, 1979 to April 30, 1980.

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TYPING GUIDE SHEET

SECTION 1

INTRODUCTION

Indiscriminate past disposal practices - the placement of waste chemicals in nonsecure ponds, lagoons, and landfills - have created serious environmental and public health problems. Indeed, it has become evident that contamination from unsecured industrial waste storage and disposal sites is a widespread problem. Often, this contamination manifests itself in the form of hazardous leachates, and contaminated ground and surface waters. These contaminant streams are diverse in terms of composition and concentration - varying from site to site, from location to location within a site, and often over time at any given location. Some contaminant streams contain a broad spectrum of organic and inorganic constituents, while others have only a few compounds of concern.

Regardless of whether contaminant streams are associated with active or abandoned sites, the need to detoxify/decontaminate these hazardous aqueous wastes sometimes arises. Moreover, since contaminant streams often are relatively dilute, a preprocessing or concentration step prior to detoxification or disposal may be necessary. However, hazardous aqueous waste treatment for this application is not a routine operation. Little information on and/or experience with concentration technology applied to hazardous leachate or contaminated groundwater exists.

This report describes portions of an ongoing project to evaluate and verify several selected concentration techniques for hazardous constituents of aqueous waste streams. The three year project entails literature search/data acquisition, desktop technology evaluations, and experimental investigations to evaluate and adapt appropriate technologies for the applications of interest. Literature search and desktop evaluations have been completed and are reported herein. At the time of this writing, experimental evaluations of selected concentration technologies are underway.

The major thrust of the initial efforts were twofold: 1) to obtain and compile data on the composition of actual contaminant streams which may require or could benefit from treatment by the concentration technologies; and 2) to collect and compile existing data on candidate concentration technologies.

Subsequent efforts involved assessing the ability of various technologies to concentrate hazardous constituents present in aqueous contaminant streams previously identified. This assessment was based upon characteristics of both the technologies and the contaminant streams. As a result of this evaluation/assessment, several process trains judged to have broad applicability were conceptualized for subsequent experimental study.

Succeeding sections of this report discuss the data gathering efforts, stepwise technology evaluations, and process train formulation efforts.

Because of the large quantity of information involved, detailed data on waste stream composition and on the treatability of 505 chemical compounds are contained in the appendices. To provide quick reference on the potential applicability of a technology to a particular compound, a summary table on chemical treatability is contained in the main body of the report.

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SECTION 2

CONCLUSIONS

WASTE STREAMS

- The most widespread hazardous waste problem faced by the public sector is contamination from unsecured waste disposal sites - generally in the form of leachates and contaminated ground and surface waters.
- There is no such thing as a "typical" hazardous waste problem - each site is unique.
- Wastes encountered are diverse in terms of composition and concentration - varying from site to site and often varying over time at any given site.
- Some waste streams contain a broad spectrum of organic and inorganic compounds, while others have only a few constituents of concern.
- Waste streams identified in this study primarily fell into one of two composition categories: high organic-low inorganic or low organic-high inorganic.
- Twenty-seven problem sites were identified in this study. The number of different problem sites where various contaminant classes were reported is as follows:

Alcohol	2
Aliphatic	4
Amine	2
Aromatic	8
Halocarbon	9
Metal	15
Miscellaneous*	11
PCB	2
Pesticide	7
Phenol	7
Phthalate	2
Polynuclear Aromatic	5

- Actual or threatened legal proceedings almost invariably

---

* See Table 2 for definition of this category

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restrict the availability of data on the nature of the problem and effectiveness of cleanup operations.

CONCENTRATION TECHNOLOGY

- Only a limited number and range of unit operations have been applied in the treatment of hazardous aqueous wastes, even though concentration technologies have been used for other applications.
- Activated carbon has been used almost exclusively for concentration of organics in the limited number of larger scale hazardous waste treatment operations.
- Concentration technology performance and operating data for industrial process wastes containing a variety of pollutants usually are reported using a surrogate parameter such as TOC or COD. Specific compound removal data are available only for a very limited number of materials.
- Limited specific information is available through vendors because much of their work is considered proprietary and/or confidential.
- Most available data on specific compound removal has been generated in laboratory and pilot scale experimental studies.
- Much of the experimental data on chemical treatability has been generated from pure compound systems. Removal from multicomponent systems may differ substantially.
- High analytical costs associated with specific compound identification will continue to restrict the data base.
- Several concentration processes are promising for treatment of hazardous aqueous wastes. However, for the application of interest, it is unlikely that any single unit process will be sufficient. In most instances, process trains must be utilized.
- Concentration technologies judged to have the greatest broad spectrum potential are chemical precipitation, flocculation, sedimentation, filtration, biological treatment, carbon adsorption, and resin adsorption.
- Reverse osmosis, stripping, and ultrafiltration are believed to have more limited and specialized applicability.

- Ion exchange for removal of inorganic species also may have potential but usually, competing processes such as chemical precipitation are more economical.

- Since hazardous waste contamination problems differ substantially from place-to-place, treatability studies in some form are almost always a prerequisite to selection of an optimum treatment approach.

SECTION 3

CHEMICAL TREATABILITY SUMMARY

An extensive amount of information on the treatability of hundreds of chemical compounds by various concentration technologies was collected. This information has been assembled in Appendix C which is organized primarily by concentration technology with the treatability of individual compounds organized according to chemical compound classification. The following concentration technologies are addressed in Appendix C:

Process	Process Code No.
Biological	I
Coagulation/Precipitation	II
Reverse Osmosis	III
Ultrafiltration	IV
Stripping	V
Solvent Extraction	VII
Carbon Adsorption	IX
Resin Adsorption	X
Miscellaneous Sorbents	XII

The chemical classification system used is described in detail later in this report; the following chemical classes are addressed in Appendix C:

Chemical Classification	Classification Code No.
Alcohol	A
Aliphatic	B
Amine	C
Aromatic	D
Ether	E
Halocarbon	F
Metal	G
PCB	I
Pesticide	J
Phenol	K
Phthalate	L
Polynuclear Aromatic	M

A total of 505 different chemical compounds are addressed in Appendix C.

TYPING GUIDE SHEET

To provide a quick reference on the treatability of each of these 505 compounds, a concise summary of information contained in Appendix C has been prepared and is presented in Table 1. Compounds are arranged in Table 1 in alphabetical order according to their chemical classification. Process and chemical classification code numbers are identical to those in Appendix C. For each compound, a summary statement describing its treatability is given with information on treatability by more than one concentration technology provided for the majority of compounds. Many compounds are known by several names. Attempts were made to use preferred or generic names according to The Merck Index. However, in some cases it was necessary to use the names which were used in the reference documents. Users of Table 1 are advised to check for compounds under several potential alphabetic listings.

An example of a typical entry in the table is that for decanol which reads "IX 100% reduction @ 100 μg/l." This should be interpreted to mean that in the referenced study, carbon adsorption effected complete removal of decanol which was initially present at a concentration of 100 μg/l.

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TABLE 1 CHEMICAL TREATABILITY SUMMARY

CHEMICAL	PROCESS - TREATABILITY	REF
A. ALCOHOLS		
Ally Alcohol	IX 22% reduction @ 100 mg/l	35
n-Amyl Alcohol	I toxic @>350 mg/l	99
(1-Pentanol)	IX 72% reduction @ 1000mg/l	35
Borneol	I 90% reduction	81
Butanol	I 70-100% reduction	56,81,99 100,101
	IX 53-100% reduction @ 0.1 to 1000 mg/l	20,35,72
	X 100% reduction @ 100μg/l	20
Sec-Butanol	I 98% reduction	81
Tert-Butanol	I 98% reduction	81,101
	IX 30% reduction @ 1000mg/l	35
1,4-Butanediol	I 99% reduction	81
Cyclohexanol	I 96% reduction	81
	IX 100% reduction @ 100μg/l	20
	X 100% reduction @ 100μg/l	20
Decanol	IX 100% reduction @ 100μg/l	20
	X 100% reduction @ 100μg/l	20
Dimethylcyclohexanol	I 92% reduction	81
1,2-Ethanediol	I depressed performance @ 484 mg/l	103
Ethanol	I 70-100% reduction @ up to 1000 mg/l	100,101 103
	III <20-100% reduction @ 1000 mg/l - dependent upon membrane	18,30
Ethanol (con't)	VII 7% reduction @ 286 mg/l	27
	IX 10% reduction @1000mg/l	20
Ethylbutanol	I 75-100% reduction	56,100, 101
2-Ethylbutanol	IX 86% reduction @1000mg/l	35
2-Ethylhexanol	I 75-85% reduction	56
	IX 98% reduction @ 700mg/l	35
2-Ethyl-1-Hexanol	IX 100% reduction @100μg/l	20
	X 100% reduction @100μg/l	20
Furfuryl Alcohol	I 97% reduction	81
m-Heptanol	IX 100% reduction @100μg/l	20
	X 100% reduction @100μg/l	20
1-Hexanol	I 70-100% reduction	56,100
m-Hexanol	IX 96% reduction @1000μg/l	35
Isobutanol	IX 42% reduction @1000μg/l	35
Isopropanol	I 70-100% reduction	56,81, 100,101
	IX 13% reduction @1000μg/l	35
Methanol	I 30-85% reduction	56,65, 100,101 103
	III 0-40% reduction @ 1000 mg/l - dependent upon membrane	18,30
	IX 4-33% reduction @15-1000 mg/l	35,72

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
4-Methylcyclohexanol	I 94% reduction	81
Octanol	I 30-75% reduction	100,101
	IX 100% reduction @ 100µg/l	20
	X 100% reduction @ 100µg/l	20
Pentanol	IX 100% reduction @ 100µg/l	20
	X 100% reduction @ 100µg/l	20
Pentarythritol	I No toxic effect	104
Phenyl methyl carbinol	I 85-95% reduction	101
Propanol	IX 100% reduction @ 100µg/l 19% reduction @ 1000mg/l	20,35
	X 100% reduction @ 100µg/l	20
i-Propanol	III 20-100% reduction @ 1000 mg/l - dependent upon membrane	18,30
m-Propanol	I 99% reduction	81
B. ALIPHATICS		
Acetaldehyde	I 30-95% reduction	56,65, 100
	IX 12% reduction @1000mg/l	35
Acetic Acid	III <20-80% reduction @1000 mg/l - dependent upon membrane	18,30
	IX 24% reduction @1000mg/l	35
Acetone	I 50-100% reduction	100,102 103
	III 15-100% reduction @1000 mg/l - dependent upon membrane	18,30
	IX 22% reduction @1000mg/l	35
Acetone Cyanohydrin	IX 30-60% reduction @100-1000 mg/l	72
Acetonitrile	I Inhibitory @ 500 mg/l	103,106
Acetylglycine	I Readily oxidized @ 500 mg/l	107
Acrolein	VII Extractable w/xylene	90
	IX 30% reduction @1000mg/l	35,90
Acrylic Acid	I 50-95% reduction	56,100, 101
	IX 64% reduction @1000mg/l	35,90
Acrylonitrile	I 70-100% reduction	56,90 107
	V Could be flash evaporated	90

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
Acrylonitrile (cont)	VII Extractable w/ethyl ether	90
Adipic Acid	I Readily oxidized @ 1000 mg/l	106
Alanine	I Readily degraded @ 500 mg/l	103
Ammonium Oxalate	I 92% reduction	81
Amyl Acetate	IX 88% reduction @ 985 mg/l	35
Butanedinitrile	I Toxic @ 500 mg/l; also reported to be readily but slowly oxidized	106,107
Butanenitrile	I Toxic @ 500 mg/l; also reported to be readily but slowly oxidized	106,107
Butyl Acetate	IX 85% reduction @ 1000mg/l	35
Butyl Acrylate	IX 96% reduction @ 1000mg/l	35
Butylene Oxide	I Degraded very slowly	107
Butyraldehyde	IX 53% reduction @ 1000mg/l	35
Butyric Acid	I 50-95% reduction; rapidly oxidized IX 60% reduction @ 1000mg/l 100% reduction @ 100μg/l X 100% reduction @ 100μg/l	56,100 106,107 20,35 20
Calcium Gluconate	I Rapidly oxidized	103

CHEMICAL	PROCESS - TREATABILITY	REF
Caproic Acid	IX 90-98% reduction @ 0.1-1000 mg/l X 50% reduction @1000mg/l	20,35 20
Caprolactam	I 94% reduction	81
Citric Acid	I Biodegradable; depressed O_2 consumption	103
Crotonaldehyde	I 90-100% reduction IX 46% reduction @1000mg/l	56,100 101 35
Cyclohexanolone	I 92% reduction	81
Cyclohexanone	I 96% reduction IX 67% reduction @1000mg/l	81 35
Cyclopentanone	I 96% reduction	81
Cystine	I Completed inhibited O_2 consumption @ 1000 mg/l	103
L-Cystine	I Slowly oxidized @ 1000 mg/l	107
Decanoic Acid	IX 100% reduction @100μg/l X 100% reduction @100μg/l	20 20
Dicyclopentadiene	IX Found to vaporize	86
Diethylene Glycol	I 95% reduction IX 26% reduction @1000mg/l	81 35
Diisobutyl Ketone	IX 100% reduction @300mg/l	35
Disopropyl Methylphosphonate	IX 98% reduction @ 2680 μg/l	86

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
Dimethyl Sulfoxide	III 63-88% reduction @ 250-1000 mg/l	18
Dipropylene Glycol	IX 16% reduction @ 1000mg/l	35
2,3-Dithiabutane	I 100% reduction @ 120µg/l	65
Dodecane	IX 100% reduction @ 100µg/l	20
	X 25% reduction @ 100 µg/l	20
Dulcitol	I Slightly inhibitory @ 1700 mg/l	109
Erucic Acid	I Oxidized @ 500 mg/l	107
Ethyl Acetate	I 90-100% reduction	56,100 101
	IX 50% reduction @ 1000mg/l	35
Ethyl Acrylate	I 90-100% reduction	56,100 101
	IX 78% reduction @ 1015mg/l	35
Ethylene Glycol	I 97% reduction	81
	IX 7% reduction @ 1000mg/l	35
2-Ethylhexylacrylate	I 90-100% reduction	56,100 101
Formaldehyde	I Conflicting data; removable & inhibitory @ 720-3000 mg/l	103,104
	III <20-80% reduction @1000 mg/l dependent upon membrane	18,30
	IX 9% reduction @ 1000 mg/l	35
Formamide	I Slowly oxidized @ 500 mg/l	107
Formic Acid	I Rapidly oxidized @ 720 mg/l	107
	IX 24% reduction @1000mg/l	35
Glutamic Acid	I Readily oxidized	103
Glycerol	III 20-100% reduction @ 1000 mg/l dependent upon membrane	18,30
Glycerine	I Readily oxidized @ 720 mg/l	103
Glycine	I Rapidly oxidized @ 720 mg/l	103
Heptane	I 90-100% reduction	56,100 101,106
Heptanoic Acid	IX 10% reduction @100µg/l	20
	X 50% reduction @100µg/l	20
Hexadecane	IX 100% reduction @100µg/l	20
	X 25% reduction @100µg/l	20
Hexylene Glycol	IX 61% reduction @1000mg/l	35
Hydracrylonitrile	I 0-10% reduction	100
Isobutyl Acetate	IX 82% reduction @1000mg/l	35
Isophorone	I 93% reduction	81
	VII Extractable w/ethyl ether	90
Isoprene	IX 86% reduction @ 500-1000 mg/l	72

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
Isopropyl Acetate	IX 68% reduction @ 1000mg/1	35
Lactic Acid	I Rapidily oxidized @ 720 mg/1	7
Lauric Acid	I Slowly oxidized @500mg/1 IX 100% reduction @ 100μg/1 X 100% reduction @ 100μg/1	107 20 20
L-Malic Acid	I Rapidly oxidized @ 500 mg/1	107
DL-Malic Acid	I Oxidized after 10-16 hr lag period	107
Malonic Acid	I Inhibitory @ 500 mg/1	107
Methyl Acetate	III 4-80% reduction @ 1000 mg/1 dependent upon membrane IX 26% reduction @ 1030 mg/1	18,30 35
Methyl Butyl Ketone	IX 81% reduction @ 988 mg/1	35
Methyl Decanoate	IX 100% reduction @ 100 μg/1 X 100% reduction @ 100 μg/1	20 20
Methyl Dodecanoate	IX 100% reduction @ 100 μg/1 X 100% reduction @ 100 μg/1	20 20
Methyl Ethyl Ketone	VII 69-88% reduction @ 12,200 mg/1 IX 47% reduction @ 1000 mg/1	27 35
Methyl Hexadecanoate	IX 100% reduction @ 100 μg/1 X 100% reduction @ 100 μg/1	20 20
Methyl Isoamyl Ketone	IX 85% reduction @ 986 mg/1	35
Methyl Isobutyl Ketone	IX 85% reduction @1000mg/1	35
Methyl Octadecanoate	IX 100% reduction @100μg/1 X 100% reduction @100μg/1	20 20
Methyl Propyl Ketone	IX 70% reduction @1000mg/1	35
Myristic Acid	IX 100% reduction @100μg/1 X 100% reduction @100μg/1	20 20
Nitrilotriacetate	I >90% reduction @500mg/1 after acclimation	111
Octadecane	IX 100% reduction @100μg/1 X 25% reduction @100μg/1	20 20
Octanoic Acid	IX 50% reduction @ 100 μg/1 X 90% reduction @ 100 μg/1	20 20
Oleic Acid	I Inhibitory	109
Oxalic Acid	I Inhibitory @ 250 mg/1	103
Pentane	I Inhibitory @ 500 mg/1	106
Pentanedinitrile	I Slowly oxidized or toxic @ 500 mg/1	106,107
Pentanitrile	I Toxic @ 500 mg/1	106
Propanedinitrile	I Toxic @ 500 mg/1	106
Propanenitrile	I Toxic @ 500 mg/1	106
B-Propriolactone	I Inhibitory @ 500 mg/1	108

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY		REF
Propionaldehyde	IX	28% reduction @ 1000 mg/l	35
Propionic Acid	IX	100% reduction @ 100 μg/l 33% reduction @ 1000 mg/l	20,35
	X	100% reduction @ 100 μg/l	20
Propyl Acetate	IX	75% reduction @ 1000 mg/l	35
Propylene Glycol	IX	12% reduction @ 1000 mg/l	35
Propylene Oxide	IX	26% reduction @ 1000 mg/l	35
Pyruvic Acid	IX	100% reduction @ 100 μg/l	20
	X	100% reduction @ 100 μg/l	20
Sodium Alkyl Sulfate	I	Readily degraded	112
Sodium Lauryl Sulfate	I	Rapidly oxidized	112
Sodium-N-Oleyl-N-Methyl Taurate	I	Readily oxidized	112
Sodium α Sulfo Methyl Myristate	I	Readily oxidized	112
Tannic Acid	I	Inhibitory	109
Tetradecane	IX	100% reduction @ 100 μg/l	20
	X	50% reduction @ 100 μg/l	20
Tetraethylene Glycol	IX	58% reduction @ 1000 mg/l	35
Thioglycollic Acid	I	Inhibitory	103
Thiouracil	I	Very slowly oxidized @ 500 mg/l	108
Thiourea	I	Inhibitory @ 500 mg/l	109
Triethylene Glycol	I	98% reduction	81
	IX	52% reduction @1000mg/l	35
Urea	I	Inhibitory @ 1200 mg/l	103
Urethane	I	Inhibitory	108
Valeric Acid	IX	80-100% reduction @ 0.1-1000 mg/l	20,35
	X	50% reduction @ 100 μg/l	20
Vinyl Acetate	IX	64% reduction @1000μg/l	35
C. AMINES			
Acetanilide	I	94% reduction	81
Allylamine	IX	31% reduction @1000mg/l	35
p-Aminoacetanilide	I	93% reduction	81
m-Aminobenzoic Acid	I	98% reduction	81
o-Aminobenzoic Acid	I	98% reduction	81
p-Aminobenzoic Acid	I	96% reduction	81

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
m-Aminotoluene	I 98% reduction	81
o-Aminotoluene	I 98% reduction	81
p-Aminotoluene	I 98% reduction	81
Aniline	I Inconsistant data; 100% reduction & inhibitory reported @ 500 mg/l III 3-100% reduction @ 1000 mg/l dependent on membrane IX 75-100% reduction @ 0.1-1000 mg/l X 100% reduction @ 100 µg/l	81,92, 108 18,30 20,35 20
Benzamide	I Initially inhibitory Slowly degraded @ 500 mg/l	107
Benzidine	I Inhibitory @ 500 mg/l; not reduced @ 1.6 µg/l IX Adsorbed	108,81 31
Benzylamine	I Inhibitory @ 500 mg/l	108
Butanamide	I Slowly oxidized @ 500 mg/l	107
Butylamine	IX 52-100% reduction @ 0.1-1000 mg/l X 100% reduction @ 100 µg/l	20,35 20
m-Chloroaniline	I 97% reduction	81
o-Chloroaniline	I 97% reduction	81
p-Chloroaniline	I 96% reduction	81
Cyclohexylamine	IX 100% reduction @100µg/l X 100% reduction @100µg/l	20 20
Dibutylamine	IX 100% reduction @100µg/l X 100% reduction @100µg/l	20 20
Di-N-Butylamine	IX 87% reduction @ 1000mg/l	35
Diethanolamine	I 97% reduction IX 28% reduction @ 996mg/l	81 35
Diethylenetriamine	IX 29% reduction @ 1000mg/l	35
Dihexylamine	IX 100% reduction @ 100µg/l X 100% reduction @ 100µg/l	20 20
Diisopropanolamine	IX 46% reduction @ 1000mg/l	35
Dimethylamine	IX 100% reduction @ 100µg/l X 100% reduction @ 100µg/l	20 20
2,3-Dimethylaniline	I 96% reduction	81
2,5-Dimethylaniline	I 96% reduction	81
3,4-Dimethylaniline	I 76% reduction	81
Dimethylnitrosamine	IX Not adsorbed	31
Di-N-Propylamine	IX 80% reduction @ 1000mg/l	35
Ethylenediamine	I 98% reduction IX 11% reduction @ 1000mg/l	81 35
N-Ethylmorpholine	IX 47% reduction @ 1000mg/l	35

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
2-Fluorenamine	I Slowly biodegraded @ 500 mg/l	108
Hexylamine	IX 100% reduction @ 100 μg/l	20
	X 100% reduction @ 100 μg/l	20
2-Methyl-5-Ethylpyridine	IX 89% reduction @ 1000 mg/l	35
N-Methyl Morpholine	IX 42% reduction @ 1000 mg/l	35
Monoethanolamine	IX 7% reduction @ 1012 mg/l	35
Monoisopropanolamine	IX 20% reduction @ 1000 mg/l	35
Morpholine	IX 100% reduction @ 100 μg/l	20
	X 100% reduction @ 100 μg/l	20
B-Napthylamine	IX Adsorbed	31
o-Nitroaniline	I ≤99.9% reduction @ 18.5 mg/l	58
p-Nitroaniline	I ≤99.9% reduction @ 6.7 mg/l	58
Octylamine	IX 100% reduction @ 100 μg/l	20
	X 100% reduction @ 100 μg/l	20
Pentanamide	I Slowly oxidized @ 500mg/l	107
p-(Phenylazo) aniline	I Inhibitory @ 500 mg/l	108
Phenylenediamine	I Toxic @ 500 mg/l	113
m-Phenylenediamine	I 60% reduction	81
o-Phenylenediamine	I 33% reduction	81
p-Phenylenediamine	I 80% reduction	81
Piperidine	IX 100% reduction @100μg/l	20
	X 100% reduction @100μg/l	20
Pyridine	IX 53% reduction @1000mg/l	35
Pyrrole	IX 100% reduction @100μg/l	20
	X 100% reduction @100μg/l	20
Thiocetamide	I Inhibitory @ 100 mg/l	103
Tributylamine	IX 100% reduction @100μg/l	20
	X 100% reduction @100μg/l	20
2,4,6-Trichloroaniline	I Readily degraded @ 500 mg/l	92,113
Triethanolamine	IX 33% reduction @1000mg/l	35
D. AROMATICS		
Acetophenone	IX 50-92% reduction @ 0.1-1000 mg/l	20,35
	X 100% reduction @100μg/l	20

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
sec-Amylbenzene	I Toxic @ 500 mg/1	113
tert-Amylbenzene	I Toxic @ 500 mg/1	113
Benzaldehyde	I Conflicting data; reported to be toxic also 99% reduction	81,108,109
	IX 50-99% reduction @ 0.1-1000 mg/1	20,35,72
	X 100% reduction @ 100 μg/1	20
Benzene	I 90-100% reduction @ up to 500 mg/1	56,100 101,114
	V 95-99% reduction	13,90
	VII 97% reduction @71-290mg/1	27
	IX 60-95% reduction @ 1 μg/1 to 1500 mg/1	6,21,31,35,38,72,90
Benzene Sulfonate	I Slowly oxidized @500mg/1	108
Benzene, Toluene, Xylene (BTX)	X 99% reduction @ 20-30 mg/1	32
Benzenethiol	I Inhibitory @ 500 mg/1	108
Benzil	IX 50% reduction @ 100 μg/1	20
	X 100% reduction @ 100 μg/1	20
Benzoic Acid	I 95-100% reduction	56,81
	IX 91-100% reduction @ 0.1-1000 mg/1	20,35
	X 100% reduction @100μg/1	20
Benzanitrile	I Inhibitory @ 500 mg/1	106
3,4-Benzpyrene	I Inhibitory @ 500 mg/1	106
sec-Butylbenzene	I Toxic @ 500 mg/1	113
tert-Butylbenzene	I Toxic @ 500 mg/1	113
Chloranil	I Inhibitory @ 10 mg/1	101
Chlorobenzene	I 100% reduction @200mg/1	66
	III 97-100% reduction @ 360 mg/1	90
	V Steam strippable	64,90
	VII 99% reduction w/chloroform solvent	90
	IX 50-95% reduction @ 1-416 mg/1	21,64,90
1-Chloro-2-Nitrobenzene	IX Adsorbed	21
Cumene	IX 100% reduction @100μg/1	20
	X 100% reduction @100μg/1	20
1,2,4,5-Dibenzpyrene	I Inhibitory @ 500 mg/1	108
m-Dichlorobenzene	I 100% reduction @200mg/1	66,92
	V Air & steam strippable	90
	VII Extractable	90
	IX 95-100% reduction @ 0.1-416 mg/1	20,90

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
m-Dichlorobenzene (cont)	X 100% reduction @ 100 µg/l	20
o-Dichlorobenzene	I 100% reduction @ 200 mg/l	66
	V Air & steam strippable	90
	VII Extractable	90
	IX 95-100% reduction @ 0.1-1000 mg/l	20,90
	X 100% reduction @ 100 µg/l	20
p-Dichlorobenzene	I 100% reduction @ 200 mg/l	66
	V Steam strippable	90
	VII Extractable	90
	IX 95-100% reduction @ 0.1-416 mg/l	20,90
	X 100% reduction @ 100 µg/l	20
1,2-Dichlorobenzene	V 70% reduction	64
1,3-Dichlorobenzene	V 80% reduction	64
1,4-Dichlorobenzene	V 90% reduction	64
	IX 60% reduction	64
3,3′-Dichlorobenzidine	IX Adsorbed	31
2,4-Dichlorophenoxyacetic Acid	I No reduction @ 174 mg/l	115
2,6-Dichlorophenoxyacetic Acid	I No reduction @ 178 mg/l	115
2,4-Dichloropropionic Acid	I No reduction @ 186 mg/l	115
Dimethylaniline (Xylidine)	IX 94% reduction @ 380 µg/l	6
7,9-Dimethylbenzacridine	I Inhibitory @ 500 mg/l	108
7,10-Dimethylbenzacridine	I Inhibitory @ 500 mg/l	108
Dinitrobenzene	III 7-81% reduction @ 30 mg/l dependent upon membrane	8
3,5-Dinitrobenzoic Acid	I 50% reduction	81
2,4-Dinitrophenylhydrazine	III 3-91% reduction @ 30mg/l dependent upon membrane	18
2,4-Dinitrotoluene	I 90-100% reduction @ 0.39-188 mg/l	81,90
	VII Extractable	90
	IX 95% reduction @ 416 mg/l	90
2,6-Dinitrotoluene	VII Extractable	90
	IX 95% reduction @ 416 mg/l	90
Ethylbenzene	I 90-100% reduction @ 0.192-105 mg/l	21,56, 100,101 114
	II 56% reduction @ 153 mg/l w/alum	21
	V 80-93% reduction	13,64, 90

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
Ethylbenzene (cont)	VII 97% reduction IX 50-84% reduction @ 1-115 mg/1	27,90 21,35 64,90
Hexachlorobenzene	I No reduction @ 200 mg/1 III 52% reduction @ 638 mg/1 V Steam strippable VII Extractable IX 95% reduction @ 416 mg/1	66,92 90 64 90 90
Hydroquinone	III 2-80% reduction @ 1000 mg/1 IX 83% reduction @ 1000 mg/1	18,30 35
Hydroxybenzenecarbonitrile	I Toxic @ 500 mg/1	106
Isophorone	IX 97% reduction @ 1000 mg/1	35,90
2-Methylbenzenecarbonitrile	I Toxic @ 500 mg/1	106
3-Methylbenzenecarbonitrile	I Toxic @ 500 mg/1	106
4-Methylbenzenecarbonitrile	I Toxic @ 500 mg/1	106
4,4′-Methylene Bis-(2-Chloroaniline)	IX Adsorbed	31
Methylethylpyridine	I 10-30% reduction	100
m-Nitrobenzaldehyde	I 94% reduction	81
o-Nitrobenzaldehyde	I 97% reduction	81
p-Nitrobenzaldehyde	I 97% reduction	81
Nitrobenzene	I Reported to be toxic @ 500 mg/1; 96-100% reduction @ 58-530 μg/1 II 34% reduction @ 160 μg/1 w/alum V Steam strippable @ 450-2160 mg/1 VII Extractable IX 95% reduction @ 1-1023 mg/1	21,58 81,108 21 64 90 21,35, 90
m-Nitrobenzoic Acid	I 93% reduction	81
o-Nitrobenzoic Acid	I 93% reduction	81
p-Nitrobenzoic Acid	I 92% reduction	81
Nitrofluorine	I Slowly oxidized @ 500 mg/1	108
m-Nitrotoluene	I 98% reduction	81
o-Nitrotoluene	I 98% reduction	81
p-Nitrotoluene	I 98% reduction	81

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY		REF
Paraldehyde	I	30-50% reduction	100
	IX	74% reduction @ 1000 mg/l	35
Pentamethyl-benzene	I	Inhibitory @ 500 mg/l	113
m-Propyl-benzene	I	Very slowly oxidized @ 37.5 mg/l	114
Pyridine	IX	47-86% reduction @ 500-1000 mg/l	35,72
Sodium Alkyl-benzene Sulfonate	I	Slowly oxidized	112
Styrene	I	70-100% reduction	100,101
	V	98-99% reduction	13
	VII	>93% reduction	27
	IX	55-97% reduction @ 20-200 mg/l	21,35 72
Styrene Oxide	IX	95% reduction @ 1000 mg/l	35
1,2,3,4-Tetra-chlorobenzene	I	74% reduction @ 200 mg/l	66
1,2,3,5-Tetra-chlorobenzene	I	80% reduction @ 200 mg/l	66
1,2,4,5-Tetra-chlorobenzene	I	@ 200 mg/l, 80% reduction @ 500 mg/l very slowly oxidized	66,113
Toluene	I	48-100% reduction @ 8µg/l to 500 mg/l; 500 mg/l was inhibitory	56,65, 100,101, 106,108, 114
	V	73-92% reduction	13,90
	VII	94-96% reduction @ 41-44 mg/l	27,90
	IX	79-98% reduction @ 0.12-317 mg/l	6,35 90
m-Toluidine	I	100% reduction	92
Toxaphene	IX	>99% reduction @ 155µg/l	66
1,2,3-Trichloro-benzene	I	100% reduction @ 200mg/l	66
	V	50% reduction	64,90
	VII	Extractable	90
	IX	70-100% reduction @ 0.1-416 mg/l	20,64 90
	X	100% reduction @ 100µg/l	20
1,2,4-Trichloro-benzene	I	100% reduction @ 200mg/l	66
1,3,5-Trichloro-benzene	I	100% reduction @ 200mg/l	66,92
2,4,6-Trichloro-phenoxyacetic Acid	I	50% reduction @ 53 mg/l	115
2,4,5-Trichloro-phenoxypropionic Acid	I	99% reduction @ 107.5 mg/l	115
2,4,6-Trinitro-toluene (TNT)	IV	80-93% TOC reduction @ 200 mg/l TOC	10
	IX	Adsorbed	2,40
	X	99% reduction @ 81-116 mg/l	2,40

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
2,6,6-Trinitrotoluene	I 50-84% reduction @100mg/l	116
Xylene	I 92-95 reduction @ 20-200 µg/l	65
	VII >97% reduction	27
	IX 68-99% reduction @ 0.14-200 mg/l	6,72
m-Xylene	I Inhibitory @ 500 mg/l	113
o-Xylene	I Inhibitory @ 500 mg/l	113
p-Xylene	I Inhibitory @ 500 mg/l	113
E. ETHERS		
bis(2-Chloroisopropyl) Ether	III 47-94% reduction @ 250 mg/l dependent upon membrane	18
	IX 100% reduction	90
bis(Chloroethyl) Ether	VII Extractable	90
	IX 50% reduction @ 94 µg/l	90
bis (Chloroisopropyl)Ether	VII Extractable w/ethyl ether & benzene	90
Butyl Ether	IX 100% reduction @ 197 mg/l	35
Dichloroisopropyl Ether	IX 100% reduction @ 1008 mg/l	35
Diethyl Ether	III 9.5-90% reduction @ 1000 mg/l dependent upon membrane	18
Diethylene Glycol Monobutyl Ether	IX 83% reduction @ 1000 mg/l	35
Diethylene Glycol Monoethyl Ether	IX 44% reduction @ 1010 mg/l	35
Ethoxytriglycol	IX 70% reduction @ 1000 mg/l	35
Ethylene Glycol Monobutyl Ether	IX 56% reduction @ 1000 mg/l	35
Ethylene Glycol Monethyl Ether	IX 31% reduction @ 1022 mg/l	35
Ethylene Glycol Monohexyl Ether Acetate	IX 66% reduction @ 100 mg/l	35
Ethylene Glycol Monohexyl Ether	IX 87% reduction @ 975 mg/l	35
Ethylene Glycol Monomethyl Ether	IX 14% reduction @ 1024 mg/l	35
Ethyl Ether	III <20-100% reduction @ 1000 mg/l dependent upon membrane	30
Isopropyl Ether	I 70-95% reduction	56,100 101
	IX 80% reduction @ 1023 mg/l	35

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY		REF
F. HALOCARBONS			
Bromochloromethane	IX	Adsorbed	21
Bromodichloromethane	V	Air & steam strippable	90
	VII	Soluble in most organics	90
	IX	Adsorbed	21,46
	X	Adsorbed @ 2 mg/l	46
Bromoform	I	100% reduction @ 0.4-1.9 μg/l	65
	IX	100% reduction @ 100μg/l	20,46
	X	100% reduction @ 100μg/l	20,46
Bromomethane	V	Air strippable	90
	VII	Soluble in most organics	90
	IX	Adsorbed	90
Carbon Tetrachloride	I	100% reduction @ 177 μg/l	21
	II	51% reduction @ 144 μg/l w/alum	21
	IX	Adsorbed	6,21,90
	X	Adsorbed	32
Chloral	V	Steam strippable @693mg/l	95
Chloral Hydrate	VII	49% reduction @15,200mg/l	27
Chloroethane	V	90% reduction by air stripping	90
	VII	Extractable w/alcohol & aromatics	90
	IX	Adsorbed	90
Chloroethylene	V	Air strippable	90
	VII	Soluble in most organics	90
	IX	Adsorbed	90
Chloroform	V	Steam strippable @ 140 mg/l	95
	IX	Adsorbed	21,46
	X	Adsorbed	32,46
Chloromethane	V	Air strippable	90
	VII	Soluble in most organics	90
Dibromochloromethane	V	Air & steam strippable	90
	VII	Extractable w/organics, ether, & alcohols	90
	IX	Adsorbed	21,46 90
	X	Adsorbed	46
Dichlorodifluoromethane	VII	Extractable w/organics, ethers, & alcohols	90
Dichloroethane	IX	Adsorbed @ 12 μg/l	6,21
1,1,-Dichloroethane	V	90% reduction w/air stripping	90
	VII	Extractable w/alcohols & aromatics	90
	IX	Adsorbed	46,90
	X	Adsorbed	46

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY		REF
1,2-Dichloro-ethane (also see Ethylene Dichloride)	I	Reduced	65
	V	Air & steam strippable	90,95
	VII	Extractable w/alcohol & aromatics	90
	IX	81% reduction @1000mg/l	90
	X	Adsorbed	46
Dichloroethylene	VII	>99% reduction @1500ppm; Kerosene & C_{10}-C_{12} effective solvents	27,95
1,1-Dichloro-ethylene	V	Air & steam strippable	90,95
	VII	Extractable w/alcohols, aromatics, & ethers	90
	IX	Adsorbed	90
1,2-Dichloro-ethylene	IX	Adsorbed	46
	X	Adsorbed	46
1,2-trans-Dichloroethylene	V	Air & steam strippable	90
	VII	Soluble in most organics	90
	IX	Adsorbed	90
Dichlorofluoromethane	IX	Adsorbed	90
Dichloro-methane	V	90% reduction w/air stripping. Steam strippable @ 800 mg/l	90,95
	VII	Soluble in most organics	90
	IX	Adsorbed	90
1,2-Dichloro-propane	V	Air & steam strippable	90
1,2-Dichloro-propane (cont)	VII	Soluble in most organics	90
	IX	93% reduction @ 1000 mg/l	90
1,2-Dichloro-propylene	V	Air & steam strippable	90
	VII	Soluble in most organics	90
	IX	Adsorbed	90
Ethylene Chloride	VII	Kerosene and C_{10}-C_{12} organics effective solvents	95
Ethylene Chloro-hydrin	VII	21% reduction @ 1640 mg/l	27
Ethylene Dichloride (also see 1,2-Dichloro-ethane)	V	99% reduction @ 8700 mg/l	66,95
	VII	94-100% reduction @ 23-1804 mg/l w/kerosene & C_{10}-C_{12} organics	95
	IX	81% reduction @ 1000 mg/l	35,95
	X	Adsorbed	32
Hexachlorobuta-diene	V	Air & steam strippable	90
	VII	Soluble in most organics	90
	IX	100% reduction @ 100 µg/l	20
	X	100% reduction @ 100 µg/l	20

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY		REF
Hexachlorocyclopentadiene	V	Polymerizes w/heat	90
Hexachloroethane	VII	Extractable w/aromatics, alcohols, & ethers	90
	IX	100% reduction @ 100 μg/l	20
	X	100% reduction @ 100 μg/l	20
Methylene Chloride	I	80-88% reduction @ 10-430 μg/l	65
	IX	73% reduction @ 190 μg/l	6
Pentachloroethane	VII	100% reduction w/kerosene solvent @ 10 mg/l	95
Perchloroethylene	V	Steam strippable @ 15 mg/l	95
	VII	Extractable w/kerosene & C_{10}-C_{12} solvents	95
Propylene Dichloride	IX	93% reduction @ 1000 mg/l	35
Tetrachloroethane	VII	Kerosene & C_{10}-C_{12} organics provided 95%	95
	IX	100% reduction @ 100 μg/l	20
	X	100% reduction @ 100 μg/l	20
1,1,1,2-Tetrachloroethane	V	Steam strippable @ 513 mg/l	95
1,1,2,2-Tetrachloroethane	V	Difficult to steam strip	95
	VII	Extractable w/aromatics, alcohols, & ethers	90
	IX	Adsorbed	90
Tetrachloroethylene	V	90% reduction by air & steam stripping	90
	VII	Soluble in most organics	90
	IX	Adsorbed	46,90
	X	Adsorbed	46
Tetrachloromethane	V	90% reduction by air & steam stripping	90
	VII	Soluble in most organics	90
Tribromomethane	V	Air & steam strippable	90
	VII	Soluble in most organics	90
	IX	Adsorbed	21,90
Trichloroacetic Acid	III	25-49% reduction @ 250 mg/l dependent upon membrane	18
Trichloroethane	VII	97-99% reduction w/kerosene & C_{10}-C_{12} solvents	95
1,1,1-Trichloroethane	I	>90% reduction @ 8-79 μg/l	65
	V	Air & steam strippable	90,95
	VII	Extractable w/alcohols & aromatics	90
	IX	Adsorbed	90
	X	Adsorbed @ 551 μg/l	46
1,1,2-Trichloroethane	I	<99% reduction @ 1305 μg/l	58
	V	Air & steam strippable	90,95

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
1,1,2-Trichloroethane (cont)	VII Extractable w/aromatics methanol, & ether	90
	IX Adsorbed	90
Trichloroethylene	I 99% reduction @ 78-214 μg/l	21,65
	II 40% reduction @ 103μg/l w/alum	21
	V Air & steam strippable	95
	VII 75% reduction w/kerosene & C_{10}-C_{12} solvents	90,95
	IX 99% reduction @ 21 μg/l	6,90
Trichlorofluoromethane	VII Extractable w/alcohols & ethers	90
	IX Adsorbed	90
Trichloromethane	V Air & steam strippable	90
	VII Soluble in most organics	90
1,2,3-Trichloropropane	IX 100% reduction @ 100μg/l	20
	X 100% reduction @ 100μg/l	20
Vinyl Chloride	I 100% reduction @ 8 μg/l	65
Vinylidene Chloride	VII 92% reduction w/kerosene & C_{10}-C_{12} solvents @ 13 mg/l	95
G. METALS		
Antimony	II 28,62,65% reduction @ 600 μg/l w/alum, lime ferric chloride coagulants	39
Arsenic	II 76-90% reduction @ 5mg/l w/ferric sulfate & lime coagulants	63,64
	IX No reduction @ 1.1 μg/l	64
	XII 96% reduction @ 25 mg/l w/silicon alloy adsorbent	
Arsenic (As^{+5})	II 94-97% reduction @ 21-25 mg/l w/alum & lime coagulant	90
Barium	I Inhibitory @ >100 mg/l	109
	II 36-99% reduction @ 0.08-5 mg/l w/lime, alum, ferric sulfate	39,63 64
	III 87-99% reduction @ 0.8-9.2 mg/l	18
	IX No reduction @ 32 μg/l	64
Beryllium	II 98-99% reduction @ 100 μg/l w/alum, lime & ferric chloride	39,90
Bismuth	II 94-96% reduction @ 600 μg/l w/alum, lime & ferric chloride	39

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
Cadmium	I Inhibitory @ 1-10 mg/l	65,90, 109
	II 45-98% reduction @ 9µg/l-5 mg/l w/lime, ferric chloride & ferric sulfate	39,63, 64
	III 90-99% reduction @ 0.1-1.0 mg/l	18
	VI Foam fractionation w/sodium dodecylbenzene sulfonate	90
	IX 6-37% reduction @ 1.8-29 µg/l	64,82
	XII 96% reduction @ 25 mg/l w/silicon alloy adsorbent	90
Chromic Acid	III 85% reduction @ 200 mg/l	24
Chromium	I 27-78% reduction @ 0.8-4 mg/l	122
	II 27-54% reduction @ 0.1-5 mg/l w/lime	16,64
	III 85-98% reduction @ 1-12 mg/l	18
	VI Reduction possible using quartenary ammonium salts	90
	IX 37-43% reduction @ 41-84 µg/l	64
	XII 100% reduction @ 300mg/l w/high clay soil adsorbent	90
Chromium (Cr^{+3})	I Complete removal	123
Chromium (Cr^{+3}) (cont)	II 98-99% reduction @ 0.7-5 mg/l w/ferric sulfate, lime, & ferric chloride	39,63
	IX 5-48% reduction @ 100 mg/l	72
Chromium (Cr^{+6})	I Inhibitory @ 100 mg/l	109
	II 22-65% reduction @ 0.7-5mg/l w/ferric sulfate, lime & ferric chloride	39,63
	IX 16-36% reduction @ 100 mg/l	72
Cobalt	I Inhibitory @ 0.08 mg/l	124
	II 18-91% reduction @ 500-800 mg/l	39
Copper	I 7-77% reduction @ 0.2-10 mg/l; reported to be inhibitory @ >0.5 mg/l	118,122 124,125
	II 67-98% reduction @ 0.2-15 mg/l w/alum, lime, ferric sulfate coagulants	16,37, 63,64, 90
	III 95-100% reduction @ 0.6-12 mg/l	18
	IV 82% reduction @0.44mg/l	59
	VI Foam fractionation w/sodium dodecylbenzene sulfonate	90
	IX 8-96% reduction @ 0.05-100 mg/l	64,72

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY		REF
Copper (cont)	XII	96-100% reduction @ 300 mg/l w/silicon alloy & high clay soil adsorbents	90
Iron	I	62% reduction @ 0.6mg/l soluble iron	126
	II	26-99% reduction @0.2-10 mg/l w/lime & ferric chloride coagulants	16,63, 64
	III	100% reduction @ 12 mg/l	18
	IV	85% reduction @ 6.8 mg/l	59
	IX	45-68% reduction @ 40-207 μg/l	64
Iron (Fe^{+2})	I	Inhibitory @ >100 mg/l	109
Iron (Fe^{+3})	I	Inhibitory @ >100 mg/l	109
Lead	I	Inhibitory @ >10 mg/l	109,124
	II	43-99% reduction @ 0.02-5 mg/l w/lime, ferric sulfate, & alum coagulants	39,63, 64,90
	III	98-100% reduction @ 0.9-12 mg/l	18
	VI	Foamfractionation w/sodium dodecylbenzene sulfate	90
	IX	13-93% reduction @ 100 mg/l; no reduction @ 5-22 μg/l	64,72
	XII	96% reduction w/silicon alloy adsorbent; redwood bark also tried	90
Manganese	I	Conflicting data; >10 mg/l inhibited while 12-50 mg/l also reported to stimulate	109,124
	II	18-98% reduction @ 0.04-5 mg/l w/lime & ferric sulfate coagulants	39,63
	IV	89% reduction @ 4.9mg/l	59
	IX	1-50% reduction @ 0.002-100 mg/l	64,72
Mercury	I	Conflicting data; 51-58% reduction @5-10mg/l & inhibitory @ any concentration	127,132
	II	25-98% reduction @ 0.001-5 mg/l w/lime & ferric chloride coagulants	39,63, 64
	VII	99% reduction @ 2 mg/l w/high molecular weight amines & quartenary salts	90
	IX	80-99% reduction @ 0.001-100 mg/l w/GAC & PAC plus chelating agent	64,72 87,90
	XII	>99% reduction using silicon alloy adsorbent	90
num Molybdenum	II	No reduction w/alum & lime; 68% reduction w/ferric chloride @ 600 μg/l	39

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
Nickel	I 0-42% reduction @ 0.3-10 mg/1	118,122, 125,128, 129
	II 10-100% reduction @ 0.9-5 mg/1 w/alum, lime, & ferric sulfate	16,39, 63,90
	III 93-97% reduction @ 12 mg/1	18
	IX 4-52% reduction @100mg/1	72
Selenium	II 0-80% reduction @ 0.002-100 mg/1 w/lime, alum, & ferric chloride coagulants	39,64, 90
	IX 96% reduction @ 500 mg/1 after GAC & lime precipitation	90
Silver	II 38-98% reduction @ 0.006-500 mg/1 w/lime, alum, & ferric chloride coagulants	39,64 90
Strontium	I No affect @ 5-50 μg/1	124
Thallium	II 30-60% reduction @ 500 μg/1 w/lime, alum, & ferric chloride coagulants	39,90
	IX 84% reduction after GAC & lime precipitation	90
Tin	II 92-98% reduction @ 500 μg/1 w/lime, alum, & ferric chloride coagulants	39
Titanium	II 96-98% reduction @ 500 μg/1 w/lime,alum, & ferric chloride coagulants	39
Vanadium	II 57-97% reduction @ 500 μg/1 w/lime, alum & ferric chloride coagulants	39
Zinc	I Reported to be inhibitory @ 0.08-1 mg/1; also 13-91% reduction reported @ 0.3-10 mg/1	90,109 118,122 124,128 131
	II 1% reduction w/alum; 37-100% reduction @ 0.3-5 mg/1 w/lime & ferric chloride coagulants	16,39, 63,64 90
	III 97-100% reduction @ 9-32 mg/1	18
	IV 79% reduction @ 1.8 mg/1	59
	IX 61-81% reduction @ 0.4-0.6 mg/1	64
	XII 99% reduction @ 10 mg/1 w/silicon oxide & calcium oxide slags as absorbents	90

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY		REF
I. PCB's			
Arochlor 1242	IX	98-99% reduction @45μg/l	8,22,38, 66
Arochlor 1254	IX	94-99% reduction @ 11-160 μg/l	8,20,22, 38,66
	X	100% reduction @ 100μg/l	20,22
Arochlor 1254 and 1260	X	23-60% reduction @ 1-25 μg/l	57
	XII	73% reduction w/PVC chips; 37% reduction w/polyurethane foam adsorbent	57
PCB's (unspecified)	IX	100% reduction @ 1-400 μg/l	6
J. PESTICIDES			
Aldrin	I	Not significantly degraded	121
	III	100% reduction	18
	IX	98-100% reduction @8-100 μg/l	6,8,20, 38
	X	100% reduction @ 100μg/l	20
Aminotriazole	I	Not significantly degraded	121
Atrazine	III	84-98% reduction	18
Atrazine (cont)	X	100% reduction@100μg/l	20
Captan	III	99-100% reduction @ 689 μg/l	18
Chlordane	I	Slightly degraded	121
	IX	97-100% reduction @ 13-1430 μg/l	6
Chlorinated Pesticides (unspecified)	X	79% reduction @ 33-118 mg/l	49
2,4-D Butyl ester	IX	100% reduction @ 100μg/l	20
	X	100% reduction @ 100μg/l	20
2,4-D & related herbicides	X	>95% reduction @ 20-1500 μg/l	32
2,4-D-Isoctyl-ester	I	Biodegradable	121
DDD	IX	99.8% reduction @ 56μg/l	8,38,66
DDE	III	100% reduction	18
	IX	>97% reduction @ 38 μg/l	8,38,66
DDT	I	Not significantly degraded	121
	II	98% reduction @ 10 μg/l w/alum coagulant	6
	III	100% reduction	18
	IX	>99% reduction @ 10-100 μg/l	6,8,20 38,66
	X	100% reduction @ 100μg/l	20

(continued)

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TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
DDVP	I Degraded	92
Diazinon	I Not significantly degraded	92,121
	III 88-98% reduction	18
Dieldrin	I Not significantly degraded	121
	II 55% reduction @ 10 µg/l w/alum coagulant	6
	III 100% reduction	18
	IX 75-100% reduction @ 19-60 µg/l	6,8,38, 66
Endrin	I Not significantly degraded	121
	II 35% reduction @ 10 µg/l w/alum coagulant	6
	IX 80-99% reduction @ 10-62 µg/l	6,8,38, 66
Endrin & Heptachlor	X >97% reduction @ 0.1-2 mg/l	32
Ferbam	I Biodegradable	121
Heptachlor	I Slightly degraded @ 500 mg/l	121
	III 100% reduction	18
	IX >99% reduction @ 6-80µg/l	6
Heptachlor-epoxide	III 99.8% reduction	18
Herbicides (unspecified)	IX 90-99% TOC reduction	38
Herbicide Orange	I 77% reduction @1380mg/l	81
Kepone	IX 100% reduction @ 4000 µg/l	6
Lindane	I Not significantly degraded	121
	II <10% reduction @ 10 µg/l w/alum coagulant	6
	III >99% reduction	18
	IX 30->99% reduction @ 10 µg/l	6
Malathion	I Not significantly degraded	92,121
	III >99% reduction	18
Maneb	I Biodegradable	121
Methyl Parathion	I Not significantly degraded	92,121
	III >99% reduction	18
Parathion	I Not significantly degraded	92,121
	II 5% reduction @ 10 µg/l w/alum	6
	III >99% reduction	18
	IX >99% reduction @ 10µg/l	6
Pentachlorophenol (Also see phenols)	I Not significantly degraded @ 75-150 mg/l	121
Propoxur	I Biodegradable	92
Randox	III 72-99% reduction	18

(continued)

✓ Ferbam

✓

22

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
Tetraethyl Pyrophosphate	I Not significantly degraded	121
Thanite	I Biodegradable	121
Toxaphene	IX 97-99% reduction @ 36-155 μg/l	6,8,38
	X >99% reduction @ 70-2600 μg/l	32
2,4,5-T ester	II 65% reduction @ 10 μg/l w/alum coagulant	6
	IX 80-95% reduction @ 10 μg/l	6
2,4,5-Trichlorophenoxyacetic Acid	I Slightly degraded @ 150 mg/l-99% reduction after 7.5 days aeration	115
Trifluralin	III 100% reduction	18
Ziram	I Slightly degraded	121
Zireb	I Slightly degraded	121
K. PHENOLS		
Bisphenol A	X >94% @ 900 mg/l when pH adjusted	23
Brine phenol	X 99% reduction of phenol @ 10-400 mg/l	33
Butyl Phenol	IX 95% reduction @ 300 μg/l	6
4-Chloro-3-Methylphenol	I Toxic @ 50-100 mg/l Inhibitory but slowly degradable @ <50 mg/l	90, 102
	VII Extractable w/benzene, alcohol, & nitrobenzene	90
	IX 100% reduction @ 100 μg/l	20
	X 100% reduction @ 100 μg/l	20
2-Chloro-4-Nitrophenol	I 72% reduction	81
Chlorophenol	V Steam strippable	90
m-Chlorophenol	I 100% reduction @ 200 mg/l	66
	X Adsorbed	66
2-Chlorophenol	I 90-95% reduction @ 150-200 mg/l	90
	III 66% reduction	90
	VII Extractable w/diisopropylether, benzene, butylacetate, & nitrobenzene	90
o-Chlorophenol	I 96-100% reduction @ 200 mg/l	66,81

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
p-Chlorophenol	I 96-100% reduction @ 200 mg/1	66,81
Cresol	IX 96% reduction @ 230 µg/1	6
m-Cresol	I 96% reduction VII 91% reduction @ 291 mg/1	81 27
o-Cresol	I 95% reduction VII 90-99% reduction @ 307-890 mg/1	81 27
p-Cresol	I 96% reduction VII 91% reduction @ 291 mg/1	81 27
2,4-Diaminophenol	I 83% reduction	81
2,4-Dibromophenol	X Adsorbed	33
Dichlorophenol	X Adsorbed	33
2,3-Dichlorophenol	IX 100% reduction @ 100 µg/1 X 100% reduction @ 100 µg/1	20 20
2,4-Dichlorophenol	I 98-100% reduction @ 60-200 µg/1 X 100% reduction @ 430 mg/1 XII Extractable w/benzene, alcohol, & nitrobenzene	81,90, 115 66 90
2,5-Dichlorophenol	I 100% reduction @ 200 mg/1	66
2,6-Dichlorophenol	I 99% reduction @ 64 mg/1	115

CHEMICAL	PROCESS - TREATABILITY	REF
Dimethylphenol	IX >99% reduction @ 1220 µg/1	6
2,3-Dimethylphenol	I 96% reduction	81
2,4-Dimethylphenol	I 94% reduction VII Extractable w/benzene & alcohol	81 90
2,5-Dimethylphenol	I 94% reduction	81
2,6-Dimethylphenol	I 94% reduction	81
3,4-Dimethylphenol	I 98% reduction	81
3,5-Dimethylphenol	I 89% reduction IX 100% reduction @ 100µg/1	81 20
4,6-Dinitro-2-Methylphenol	VII Extractable w/benzene & acetone	90
2,4-Dinitrophenol	I 85% reduction VII Extractable w/benzene & alcohol IX Adsorbed	81,117 90 21
B-Napthol	X 100% reduction @ 100µg/1	20
m-Nitrophenol	I 95% reduction	81
o-Nitrophenol	I 97-98% reduction	58,81
2-Nitrophenol	VII Extractable w/benzene & alcohol	90

(continued)

21

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
p-Nitrophenol	I 95-99% reduction	58,81
	X >99% reduction @ 700-1800 mg/l	23,33
4-Nitrophenol	III Removable	90
	VII Extractable w/benzene & alcohol	90
Nonylphenol	IX Adsorbed	21
Pentachlorophenol	I 26% reduction @ 200 mg/l	66,92
	VII Extractable w/benzene, alcohol & nitrobenzene	90
	IX 100% reduction @ 10 mg/l	6,21
	X 100% reduction @ 100 μg/l	20
Phenol	I 62-100% reduction @ 5-500 mg/l; reported to be inhibitory @ 500 mg/l	58,66, 88,90, 92,106, 108,118, 119
	III -6 - 100% reduction @ 1-1000 mg/l dependent upon membrane	18,30 54,90
	IV 75% reduction @ 1-100mg/l	54
	V Steam strippable	90
	VII 4-98% reduction @ 67-8800 mg/l	27,90
	IX 80-100% reduction @ 0.1-1200 mg/l	6,20,21 35,38, 72,90,
	X >99% reduction @ 500-5000 mg/l	23,33
p-Phenylazophenol	I Inhibitory @ 500 mg/l	108
Resorcinol	IX 100% reduction @100μg/l	20
	X 100% reduction @100μg/l	20
Sodium Pentachlorophenol	I No reduction @ 15 mg/l	120
2,3,5-Trichlorophenol	I 100% reduction @200mg/l	66,92
2,4,5-Trichlorophenol	I 99% reduction @ 19 mg/l	115
2,4,6-Trichlorophenol	I 100% reduction @ 20-200 mg/l; reported to be inhibitory @ 50-200 mg/l	66,90, 102,115
	VII Extractable w/benzene, alcohol, nitrobenzene	90
	IX 100% reduction @100μg/l	20
	X 100% reduction @ 0.1-510 mg/l	20,66
Trimethylphenol	IX 92% reduction @ 130 μg/l	6
Xylenol	VII 96% reduction @ 227 mg/l	27

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS - TREATABILITY	REF
L. PHTHALATES		
Bis(2-Ethylhexyl)Phthalate	I 70-78% reduction @ 5mg/l	90
	II 80-90% reduction @ 0.5-3.5 µg/l w/aluminum sulfate coagulant	90
	VII Extractable w/ethyl ether & benzene	90
	IX >98% reduction @ 1300µg/l	5,90
Butylbenzyl Phthalate	I Biodegradable	90
	VII Extractable w/ethyl ether & benzene	90
Dibutyl Phthalate	IX 100% reduction @ 100 µg/l	20
	X 100% reduction @ 100 µg/l	20
Di-N-Butyl Phthalate	I Biodegradable @ 200 mg/l	90
	II 60-70% reduction @ 2.5-4.5 µg/l w/aluminum sulfate	90
	VII Extractable w/ethyl ether & benzene	90
Diethyl Phthalate	II Biodegradable	90
	VII Extractable w/ethyl ether & benzen	90
Diethylhexyl Phthalate	X 100% reduction @ 100 µg/l	20
Di(2-ethylhexyl)Phthalate	I 50-70% reduction	100
Dimethyl Phthalate	I Degradable; 100% reduction @ 215 µg/l	21,90
	II 15% reduction @ 183µg/l w/alum	21
	VII Extractable w/ethyl ether & benzene	90
	IX 100% reduction @100µg/l	20
	X 100% reduction @100µg/l	20
Di-N-Octyl Phthalate	I Biodegradable @ 63 mg/l	90
	VII Extractable w/ethyl ether & benzene	90
Isophthalic Acid	I 95% reduction	81
Phthalimide	I 96% reduction	81
Phthalic Acid	I 97% reduction	81
M. POLYNUCLEAR AROMATICS		
Acenaphthalene	X 100% reduction @100µg/l	20
Acenaphthene	II Precipitated w/alum	90
Acenaphthylene	II Precipitated w/alum	90
Anthracene	I Toxic @ 500 mg/l	108
	VII Extractable w/toluene	90

(continued)

TABLE 1 (continued)

CHEMICAL	PROCESS	TREATABILITY	REF
Benzanthracene	I	Slowly oxidized @ 500mg/l	108
	II	Separable by gravity or sand filtration	90
11,12-Benzofluoranthene	II	Separable by gravity or sand filtration	90
Benzoperylene	I	Biodegradable	90
1,12-Benzoperylene	II	Separable by gravity or sand filtration	90
Benzo(a)-pyrene	II	Separable by gravity or sand filtration	90
Biphenyl	IX	100% reduction @ 100 μg/l	20
	X	100% reduction @ 100 μg/l	20
D-Chloramphenicol	I	86% reduction	81
2-Chloronapthalene	II	Precipitated w/alum	90
Chrysene	II	Separable by gravity & sand filtration	90
Cumene	IX	100% reduction @ 100 μg/l	20
	X	100% reduction @ 100 μg/l	20
α,α-Diethylstilbenediol	I	Inhibitory	108
9,10-Dimethylanthracene	I	Degradable @ 500 mg/l	108
9,10-Dimethyl-1,2-benzanthracene	I	Slowly oxidized @ 500 mg/l	108
Dimethylnapthalene	IX	80% reduction @ 100μg/l	20
	X	100% reduction @100μg/l	20
1,1,-Diphenylhydrazine	IX	Adsorbed	31
1,2-Diphenylhydrazine	I	28% reduction @ 341μg/l	81
Fluoranthrene	IX	80% reduction @ 100μg/l	20
	X	100% reduction @100μg/l	20
7-Methyl-1,1-benzanthracene	I	Inhibitory @ 500 mg/l	108
20-Methylcholanthrene	I	Toxic or inhibitory; able to undergo slow biological oxidation @ 500 mg/l	108
Napthalene	I	85-95% reduction; Inhibitory @ 500 mg/l	56,101, 108
	II	Separable by gravity or sand filtration	90
	V	Air strippable by 50:1 volume of air	90
	IX	70% reduction	31,64
Phenanthrene	IX	80% reduction @ 100μg/l	20
	X	100% reduction @100μg/l	20
2,3-o-Phenylene Pyrene	II	Separable by gravity or sand filtration	90
Pyrene	II	Separable by gravity or sand filtration	90
	IX	80% reduction @ 100μg/l	20
	X	100% reduction @100μg/l	20

SECTION 4

WASTE STREAM IDENTIFICATION AND CHARACTERIZATION

PROBLEM TYPES

One of the early activities undertaken in this project was an effort to identify actual hazardous aqueous waste problems faced by the public sector which might benefit from the application of concentration technology. This effort was accomplished primarily through personal contacts with governmental entities and companies involved in hazardous waste management since little published information existed. Appendix A contains a list of entities contacted. In many cases there were several contacts within the entity listed.

Individuals contacted were queried about major problems known to them in terms of hazardous materials in aqueous solutions and specifically, priority pollutants. The predominant response was that discharge from waste storage and disposal sites were the biggest problem.

Responders indicated that these discharges, generally leachate, were becoming more numerous and severe, and will become more prevalent as wastewater pretreatment regulations are enforced and greater volumes of residues containing concentrated hazardous materials are produced. Because of the current deficiency in the number of controlled landfills, many sludges and hazardous materials will not receive adequate disposal, and additional discharge and leachate problems can be expected.

Even though there is no such thing as a typical hazardous waste problem, and each site is unique, problems generally can be grouped into three broad categories: 1) land disposal sites; 2) container storage and disposal sites; and 3) lagoons.

Land disposal sites range from simple dumps to fully secured chemical landfills, and can be actively operated or abandoned and inactive. Although there are landfills devoted exclusively to industrial wastes, many co-dispose municipal and industrial liquids, sludges and solid wastes together. Responsibilities and assignment of potential liabilities for active landfills are fairly clear, but for inactive or abandoned sites responsibility usually devolves to some governmental entity.

Container storage and disposal sites represent a considerable problem. Only recently has the magnitude and potential danger been recognized. In some cases, containers have been breached and concentrated wastes flowed into surface and ground waters. This has been a cause for grave concern, because some container disposal sites encompass many acres and thousands of barrels, drums, tanks, etc. Many containers are in various stages of progressive failure, thus constituting potential problems of enormous magnitude and complexity. For example, conjunctive disposal of containers of corrosive, reactive, flammable, and toxic materials could result in breaching in "domino" fashion if there is failure and leakage from very few. Examples of such situations have been uncovered during the interviews. In one case, excavation of buried drums ceased after several underground detonations.

Most lagoons which cause problems are unlined. Evidence that the integrity of a disposal lagoon has been breached is found as ground or surface water contamination. Such contamination occurs by: 1) vertical percolation, 2) overland flow, or 3) flood flushing. In the case of vertical percolation, wastes are transported through the porous lagoon bottom, through the soil vadose zone, and into the ground water table. Overland flow involves a combination of horizontal percolation and chronic lagoon overflows to surface water. In contrast, flood flushing entails acute release of lagoon contents because of an extreme rainfall event or dike failure.

Occasional discharges of hazardous wastes to municipal sewerage systems have been reported. These generally resulted from spill incidents, either accidental or intentional. While some such discharges have been porblems, those interviewed regarded the leachate and discharge problem as being far more important.

Three other potentially significant problems were considered for inclusion in this project: 1) drum and container contents, 2) waste-contaminated lagoon contents, and 3) sludges. In the first two instances, although neither is dilute, often the wastes can be concentrated further. On the other hand, sludges were deemed important to this project only in terms of the degree to which they are leached or their liquid component drains to ground and/or surface water.

Upon consideration of all of the available information, it was decided to focus primarily on leachate and contaminated ground and surface waters associated with hazardous waste disposal sites. This decision largely was based upon the fact that leachate contamination is believed by knowledgeable individuals to be the largest and most pressing of the cited problems. Moreover, little available data exists on leachate treatment for hazardous waste repositories and industrial disposal sites. Thus, this project can contribute to plugging the information gap.

WASTE STREAM COMPOSITION

Having set the focus of the project on leachates, and contaminated ground and surface waters, an effort was launched to obtain composition data on known problem sites. This effort was complicated by several factors: 1) little published information exists, 2) record-keeping and reporting procedures for hazardous waste problems are sketchy, 3) actual or potential litigation causes data to be restricted, 4) because of lack of funding only the most severe problems have received attention, and 5) high analytical costs associated with specific organic compound identification often causes measurement and reporting of surrogate parameters such as TOC, COD, and BOD.

Despite the above cited problems, it was possible to obtain composition data on leachates, and contaminated ground and surface waters in the proximity of 27 sites containing hazardous wastes. Much of the obtained data is unpublished.

Because of the large quantity of data, this information is summarized in Appendix B, Table B-1. In addition to data on the 27 sites, this table contains summary data on 43 industrial disposal sites which were surveyed in a previous study (127). There is a wide variation from site to site in the detail and completeness of the data contained in Table B-1 since relatively few waste streams have been well characterized. Nevertheless, this data compilation represents the best available information and is believed to be one of the most complete available at this time.

Study of the compiled data shows that wastes encountered are diverse in terms of composition and concentration. Some contain a broad spectrum of organic and inorganic materials, while others may have only a limited number of compounds. A wide variability in waste composition is observed from site to site. Moreover, waste composition often is highly variable at any given site with respect to both time and location.

WASTE CONSTITUENT CLASSIFICATION

Because of the large number of chemicals and possible combinations and permutations of constituents in hazardous waste streams, it would be desirable to employ predictive techniques to forecast the behavior of chemicals present in such waste streams. Unfortunately, no proven method exists to accurately predict the removability of all of the potential chemical constituents of hazardous aqueous waste streams.

Nevertheless, some grouping or classification of waste stream constituents was deemed desirable to extend the usefulness of the data and facilitate the evaluation of concentration technology. Therefore, a contaminant classification system was formulated as given in Table 2. This classification system was based upon the twelve groups of compounds that were used to classify the 129 priority pollutants that resulted from the 1976 Flannery Consent Decree (NRDC vs. Train, June 1976). The slightly modified categories given in Table 2 were considered a better reflection of compounds actually detected at identified hazardous waste contamination sites. All of the identified constituents of the actual hazardous waste streams given in Table B-1 have been classified according to this system. The results of this classification effort together with an indication of the frequency of identification of each constituent is given in Table 3. The number of different sites where compounds in each classification were identified is given below:

Alcohol	2
Aliphatic	4
Amine	2
Aromatic	8
Halocarbon	9
Metal	15
Miscellaneous	11
PCB	2
Pesticide	7
Phenol	7
Phthalate	2
Polynuclear Aromatic	5

This classification system was used to aid in the technology screening effort as described in a subsequent section of this report.

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TABLE 2

CONTAMINANT CLASSIFICATION SYSTEM

1. Alcohol
2. Aliphatic
3. Amine
4. Aromatic - nonhalogenated and halogenated aromatic compounds
5. Ether
6. Halocarbon - halogenated aliphatic compounds
7. Metal
8. Miscellaneous - including selected priority pollutants, pH, BOD, TOC, COD, chloride, sulfate, phosphate, and other parameters generally used to characterize wastewaters
9. PCB
10. Pesticide
11. Phenol - including chloro and nitro phenols
12. Phthalate
13. Polynuclear Aromatic

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TABLE 3

SUMMARY LIST OF CONTAMINANTS REPORTED

CONTAMINANT CLASSIFICATION	CONTAMINANT	CONCENTRATION RANGE REPORTED	NO. OF SITES REPORTED
Alcohol	Chlorobenzyl alcohol	P	1
	Ethanol	56.4 mg/l	1
	2-ethylhexanol	19,000 - 23,000 μg/l	1
	Isopropanol	<0.1 mg/l	1
	Methanol	42.4 mg/l	1
Aliphatic	Acetone	50.3 mg/l	1
	Dicyclopentadiene	80 - 1200 μg/l	1
	Diisopropylmethylphosphonate	400 - 3600 μg/l	1
	2-ethylhexanol	ND - 4500 μg/l	1
	3-heptanone	ND - 1300 μg/l	1
	Hexachlorocylohexane*		
	alpha isomer*	ND - 600 μg/l	1
	beta isomer*	ND - 70 μg/l	1
	gamma isomer*	ND - 600 μg/l	1
	delta isomer*	ND - 120 μg/l	1
	Methyl isobutyl ketone	2000 μg/l	1
	Paraffins	P	1
	Pinene	P	1
Amine	benzylamine or o-toluidine	<10 - 471 μg/l	1
	n-nitrosodiphenylamine	190 μg/l	1
Aromatic	m-acetonylanisol[a]	<3 - 1357 μg/l	1
	Aniline	140 - 870 μg/l	1
	Benzaldehyde	P	1
	Benzene*	6 - 7370 μg/l	4
	Benzene hexachloride	P	1
	Benzoic acid	<3 - 12,311 μg/l	1
	Camphene	P	1
	Camphor	<10 - 7571 μg/l	1
	Chloraniline	<10 - 86 μg/l	1
	o-chloroaniline	ND - 360 μg/l	1

(continued)

TABLE 3 (continued)

CONTAMINANT CLASSIFICATION	CONTAMINANT	CONCENTRATION RANGE REPORTED	NO. OF SITES REPORTED
Aromatic (continued)	Chlorobenzaldehyde	P	1
	Chlorobenzene*	4.6 - 4620 µg/l	4
	4-chloro-3-nitro benzamide	440 - 8700 µg/l	1
	p-chloronitrobenzene	460 - 940 µg/l	1
	Chloronitrotoluene	ND - 460 µg/l	1
	p-chlorophenyl methyl sulfide	<10 - 68 µg/l	1
	p-chlorophenyl methyl sulfone	<10 - 40 µg/l	1
	p-chlorophenyl methyl sulfoxide	<10 - 53 µg/l	1
	2,6-dichlorobenzamide	890 - 30,000 µg/l	1
	Dichlorobenzene*	<10 - 517 µg/l	2
	Dimethyl aniline	<10 - 6940 µg/l	1
	m-ethylaniline	<10 - 7640 µg/l	1
	Ethyl benzene*	3.0 - 470 µg/l	2
	Hexachlorobenzene*	32 - <100 µg/l	2
	p-isobutylamisol[a] or p-acetonylanisol[a]	<3 - 86 µg/l	1
	Limonene	P	1
	Nicotinic acid	P	1
	o-nitroaniline	170,000 - 180,000 µg/l	1
	p-nitroaniline	32,000 - 47,000 µg/l	1
	Nitrobenzene*	ND - 740 µg/l	1
	Styrene	P	1
	Toluene*	<5 - 31,000 µg/l	4
	1,2,4-trichlorobenzene*	<10 - 28 µg/l	2
	Trimethylbenzene	P	1
	Xylene	P - 3300 µg/l	1

(continued)

TABLE 3 (continued)

CONTAMINANT CLASSIFICATION	CONTAMINANT	CONCENTRATION RANGE REPORTED	NO. OF SITES REPORTED
Halocarbon	C_4 alkyl cyclopentadiene	P	1
	Bromodichloromethane*	ND - 35 μg/l	1
	Chloroform*	0.02 - 4550 μg/l	3
	C_5 substituted cyclopentadiene	P	1
	Dibromochloromethane*	3.9 μg/l	1
	1,1-dichloroethane*	<5 - 14,280 μg/l	1
	1,2-dichloroethane*	2.3 - 330 μg/l	4
	trans-1,2-dichloroethane*	25 - 8150 μg/l	2
	1,1-dichloroethylene*	28 - 19,850 μg/l	4
	1,2-dichloroethylene*	0.2 μg/l	1
	Dichloromethane*	3.1 - 6570 μg/l	4
	Dichloropropene*	P	1
	Hexachlorobutadiene*	<20 - 109 μg/l	2
	Hexachlorocyclopentadiene*	<100 μg/l	1
	Octachlorocyclopentene	<100 μg/l	1
	Perchloroethylene*	ND - 1000 μg/l	1
	1,1,2,2-tetrachloroethane*	<5 - 1590 μg/l	1
	Tetrachloroethene	<1 - >50,000 μg/l	1
	Tetrachloroethylene*	23 - 590 μg/l	3
	Tetrachloromethane*	<1 - 25,000 μg/l	2
	Tribromomethane*	0.2 μg/l	1
	Trichloroethane*	P - 490 μg/l	1
	1,1,1-trichloroethane*	1.6 - 532 μg/l	4
	1,1,2-trichloroethane*	<5 - 870 μg/l	2
	Trichloroethene	<3 - 10,000 μg/l	3
	Trichloroethylene*	760 - 260,000 μg/l	3
	Trichlorofluoromethane*	<5 - 18 μg/l	1
	Trichloromethane*	<1 - <10,000 μg/l	1
	Vinyl chloride*	140 - 32,500 μg/l	1

(continued)

TABLE 3 (continued)

CONTAMINANT CLASSIFICATION	CONTAMINANT	CONCENTRATION RANGE REPORTED	NO. OF SITES REPORTED
Metal	Ag*	1 - 10 µg/l	2
	Al	0.124 mg/l	1
	As*	0.011 - >10,000 mg/l	6
	Ba	0.1 - 2000 mg/l	5
	Be*	0.007 mg/l	1
	Bo	0.624 mg/l	1
	Ca	164 - 2500 mg/l	4
	Cd*	0.005 - 8.2 mg/l	6
	Co	0.01 - 0.22 mg/l	1
	Cr*	<0.001 - 208 mg/l	7
	Cu*	0.001 - 16 mg/l	9
	F	0.14 - 1.3 mg/l	1
	Fe	0.090 - 678 mg/l	6
	Hg*	0.0005 - 0.007 mg/l	7
	K	6.83 - 961 mg/l	3
	Mg	25 - 453 mg/l	3
	Mn	0.01 - 550 mg/l	4
	Mo	0.1 - 0.24 mg/l	3
	Na	4.6 - 1350 mg/l	5
	Ni*	0.02 - 48 mg/l	4
	Pb*	0.001 - 19 mg/l	6
	Sb*	2 mg/l	1
	Se*	0.003 - 0.59 mg/l	4
	Zn*	0.024 - 240 mg/l	10
Miscellaneous	Alkalinity, as $CaCo_3$	20.6 - 5400 mg/l	3
	BOD_5	42 - 10,900 mg/l	3
	Cl	3.65 - 9920 mg/l	6
	CN	0.0005 - 14 mg/l	2
	COD	24.6 - 18,600 mg/l	5
	color	50 - 4000	1
	Halogenated Organics	0.002 - 15.9 mg/l	1

(continued)

TABLE 3 (continued)

CONTAMINANT CLASSIFICATION	CONTAMINANT	CONCENTRATION RANGE REPORTED	NO. OF SITES REPORTED
Miscellaneous (continued)	Hardness, as $CaCo_3$	700 - 4650 mg/l	2
	Heavy Organics	0.01 - 0.59 mg/l	1
	Light Organics	1.0 - 1000 mg/l	1
	MBAS	0.24 mg/l	1
	NH_3-N	<0.010 - 1000 mg/l	3
	NH_4-N	0.65 mg/l	1
	NO_2-N	<0.010 - <.1 mg/l	2
	NO_3-N	0.010 - <.1 mg/l	3
	Oil & Grease	90 mg/l	1
	pH	∿3 - 7.9	7
	PO_4	<0.010 - 2.74 mg/l	4
	SO_4	1.2 - 505 mg/l	4
	SOC	4200 mg/l	1
	Specific Conductance	80 - 2000 mg/l	2
	SS	<3 - 1040 mg/l	4
	Sulfide	<0.1 mg/l	1
	TDS	1455 - 15,700 mg/l	4
	temperature	58 - 63°F	1
	TKN	<1 - 984 mg/l	4
	TOC	10.9 - 4300 mg/l	7
	Total Inogranic Carbon	71 mg/l	1
	Total P	<0.1 - 3.2 mg/l	2
	Total Solids	159 - 1730 mg/l	1
PCB's	Aroclor 1016*/1242*	110 - 1900 μg/l	1
	Aroclor 1016*/1242*/1254*	66 μg/l - 1.8 g/l	1
	Aroclor 1242*/1254*/1260*	0.56 - 7.7 μg/l	1
	Aroclor 1254*	70 μg/l	1
Pesticide	Aldrin*	<2 - <10 μg/l	2
	Carbofuran	P	1
	DDT*	4.28 - 14.26 μg/l	1
	Dieldrin*	<2 - 4.5 μg/l	1

(continued)

TABLE 3 (continued)

CONTAMINANT CLASSIFICATION	CONTAMINANT	CONCENTRATION RANGE REPORTED	NO. OF SITES REPORTED
Pesticide (continued)	Endrin*	<2 - 9 µg/l	1
	Heptachlor*	573 µg/l	1
	Kepone	2 mg/l	1
	Nemagon	<1 - 8 µg/l	1
Phenol	p-2-oxo-n-butylphenol	<3 - 1546 µg/l	1
	o-sec-butylphenol[a]	<3 - 83 µg/l	1
	p-sec-butylphenol[a]	<3 - 48 µg/l	1
	2-chlorophenol*	3 µg/l - 20 µg/l	2
	Dimethylphenol	<3 µg/l	1
	2,4-Dinitrophenol*	10 - 99 µg/l	2
	1-ethylpropylphenol[a]	<3 µg/l	1
	Isoprophylphenol[a]	<3 - 8 µg/l	1
	o-nitrophenol*	8600 - 12,000 µg/l	1
	Pentachlorophenol*	2.4 mg/l	1
	Phenol*	<3 - 17,000 µg/l	4
	Phenols*	0.008 - 54.17 µg/l	1
	2,4,5-trichlorophenol	P	1
Phthalate	Phthalate esters	P	1
	Phthalates*	P	1
Polynuclear Aromatic	Biphenyl napthalene	P	1
	Methyl napthalene	<10 - 290 µg/l	1
	Napthalene*	<10 - 66 µg/l	1
	Petroleum oil	P	1
	Phenanthrene* or anthracene	<10 - 670 µg/l	1
	Polynuclear aromatics	3400 µg/l	1

ND - not detected
P - present, but not quantified
a - structure not validated by actual compound
* - Priority Pollutant

SECTION 5

TECHNOLOGY EVALUATION APPROACH

An iterative approach was deemed to be the most effective means of evaluating technologies with potential application to concentration of hazardous constituents of aqueous waste streams. Moreover, although it was recognized that, ultimately, process trains must be evaluated, it was considered most reasonable to begin with an examination of unit processes. Thus, unit processes were screened in increasing levels of detail until there was sufficient justification to either reject or carry forward the process. Technologies which survived the screening then were incorporated in process trains which were subjected to desktop analysis of their ability to treat actual waste streams. Waste streams were selected from those identified in the previously described waste stream characterization portion of this study.

The initial step in the evaluation consisted of identifying technologies with potential application to concentration of hazardous constituents of aqueous wastes. Thus, early in the project, the following list of candidate technologies was developed:

- Biological Treatment
- Carbon Adsorption
- Catalysis
- Centrifugation
- Chemical Precipitation
- Crystallization
- Density Separation
- Dialysis/Electrodialysis
- Distillation
- Evaporation
- Filtration
- Flocculation
- Ion Exchange
- Resin Adsorption
- Reverse Osmosis
- Solvent Extraction
- Stripping
- Ultrafiltration

Technology profiles then were prepared for each of the candidate unit processes. The focus of this step was on the characteristics of the technology without regard to specific waste streams to be treated. Factors considered in development of the technology profiles included:

- state of development,
- range of technology application,
- process flexibility,
- process reliability,
- economic and engineering constraints in technology modification and application
- start-up requirements,
- efficiency,
- specific limitations,
- energy requirements,
- form of concentrated material, and
- environmental acceptability.

Technology profiles formed the basis for the initial screening of the applicability of individual technologies to concentration of hazardous constituents of aqueous wastes. At this point, certain technologies were eliminated from further consideration for reasons discussed in the individual technology profiles. Remaining technologies were carried forward for more detailed review.

The next step in the evaluation process was an extensive literature review which focused on the technologies which survived the initial screening and upon chemical compounds in the classes identified in the preceding section of this report as having been identified as constituents of actual hazardous aqueous waste streams.

Since it was evident that no single unit process would be sufficient in itself to adequately treat the diverse waste streams in question, five candidate process trains were formulated as being most broadly applicable to the types of waste streams identified in Table B-1. In addition, two actual waste stream compositions were selected from this table for use in the next step in the technology screening. A third waste stream composition was hypothesized subsequent to examination of all of the available composition data. It is believed that the three selected waste stream compositions cover a range of constituents and concentrations representative of actual problems likely to be encountered.

A desktop analysis then was performed to assess the ability of each of the five process trains to treat each of the three waste streams.

Simultaneously, selected vendors were requested to evaluate the ability of their technology to adequately treat the three waste streams in question.

The results of these evaluations provide a basis for making an initial judgment on the applicability of a given concentration technology to specific situations in the absence of expermental data. In addition, these evaluations were utilized to select and arrange technologies in priority order for experimental study in the next phase of this project.

Subsequent sections of this report discuss each of the steps in the technology evaluation in detail.

SECTION 6

TECHNOLOGY PROFILES

This section contains brief descriptions of each of the candidate technologies together with an initial assessment of the potential applicability of each technology to concentration of hazardous constituents of aqueous waste streams. The focus here is on the characteristics of the technology without regard to specific waste streams to be treated.

Each technology is described and past applications are indicated. No attempt has been made to provide detailed information on the theory, design or operation of the technologies since such information is readily available in standard texts and design manuals. Rather, the basic features of the technologies are highlighted and the potential for the application of interest is assessed.

BIOLOGICAL TREATMENT

Process Description

Biological treatment involves the utilization of microorganisms to decompose organic matter present in wastewater. The microorganisms metabolize the organic matter to yield energy for snythesis, motility and respiration. Biological utilization of organic compounds involves a series of enzyme-catalyzed reactions. Simple dissolved or soluble organic compounds are readily incorporated into the cells of microorganisms and oxidized. When microbial cells come into contact with complex organics, extracellular enzymes are released outside the cells to hydrolyze high molecular weight materials into diffusible fractions, enabling their transport through the cell wall for assimilation. Thus the larger, more complex organic compounds are metabolized at a much slower rate. Although microorganisms may be adapted and grown on many types of organic materials, there are some complex organic compounds that will not be removed by biological oxidation; and these are called "refractory" organic compounds.

Inorganics may be partially removed from the liquid phase and concentrated in the biomass during biological treatment through the mechanism of adsorption. However, inorganics are not destroyed by biological treatment and, in fact, at higher concentrations may be inhibitory to biological processes.

Biological systems can take a variety of forms. A primary distinction is the mode of respiration and synthesis - aerobic or anaerobic. Aerobic biological processes employ microorganisms which require oxygen for their existence while anaerobic processes are carried out in the absence of oxygen. The former processes proceed more rapidly and produce larger quantities of biomass residual than the latter.

Three types of aerobic systems are of primary concern in the current context: trickling filter, activated sludge, and lagoons.

1. Trickling Filter Process - The trickling filter process consists of a fixed bed of supporting media (e.g., crushed rock, plastic medica, redwood slats) upon which a biological slime layer is grown. Wastewater is intermittently or continuously applied to the top of the filter and flows downward through the filter, passing over the layer of microorganisms. Dissolved organic material and nutrients in the wastewater are taken up by the zoogleal film layer for utilization by the microbial population. Oxidized end products are released back to the liquid. A trickling filter will operate properly as long as the void spaces are not clogged by solids or excessive growth of the biological film layer. The biological film layer grows and gradually increases in thickness to the point that hydraulic shear force from the downward flow of wastewater causes portions of the film layer to slough off the filter media.

2. Activated Sludge Process - The activated sludge process, in one of its several modifications, is probably the most commonly used aerobic biological waste treatment process. It is dependent upon the maintenance of a flocculant suspension of microorganisms which is dispersed in intimate contact with the waste to be treated. In operation of the activated sludge process, wastewater containing soluble organic compounds is fed to an aerobic reactor (aeration tank) which furnishes (1) air required by microorganisms to biochemically oxidize the waste organics, and (2) mixing to insure intimate contact of microorganisms with the organic waste. The aerobic reactor contents are referred to as mixed liquor. In the vigorously mixed aerobic reactor, the organic wastes are metabolized to provide energy and growth factors for the production of more microorganisms with the release of carbon dioxide and water as metabolic end products. Organic waste compounds are thus degraded to innocuous end products and microorganisms. Mixed liquor flows from the aeration tank to a sedimentation tank, which provides quiescent settling to allow separation of the biological solids from the treated wastewater. The treated and clarified water is collected and discharged as process effluent. Most of the settled biological solids are recycled as return activated sludge back to the aerobic reactor

to provide an activated mass of microorganisms for continuous treatment of incoming wastewater. Some of the settled biological solids are wasted to maintain a proper balance in the population of microorganisms in the mixed liquor of the aerobic reactor. Recycling and wasting of biological solids (microorganisms) from the reactor assures a proper ratio of incoming waste to the population of microorganisms (food to microorganisms, or F/M ratio), which is critical to efficient biodegradation of soluble organic waste compounds.

3. Lagoons - The use of lagoons as a biological treatment technique provides an attractive option where land costs are relatively low. Several types of lagoons are possible, but they all share some basic features.

A long residence time for the incoming wastewater (in excess of 7-10 days) provides sufficient time for sedimentation of solids to occur. The long residence time provides an opportunity for biological decomposition of degradable organic material. In some lagoons, mechanical aeration may be provided to enhance oxygen concentrations; other lagoons may provide no aeration, but may rely solely upon natural processes such as air-water transport, and photosynthetic oxygen production by algae. In the latter types of lagoons, especially in deeper situations, the lagoon bottom may become anaerobic, and some of the properties described for anaerobic processes may pertain.

Climatic conditions may limit the application of lagoons to areas or seasons where icing conditions do not prevail.

The capability of anaerobic biological processes to degrade many organic compounds is less than that of aerobic processes, as is the rate of degradation. However, anaerobic biological processes are attractive for the more readily degraded compounds in concentrated form, inasmuch as the relative energy costs may be less for these processes, as compared with aerobic biological processes, and they offer the possibility for energy recovery in the form of methane gas production. Furthermore, rather than producing excess sludge, as in the aerobic processes, the anaerobic processes generally may be operated at levels of negligible solids production.

Anaerobic degradation typically has been used for treatment of sludges. However, more recently attention has been given to treatment of aqueous organic wastes of widely varying strengths by anaerobic processes. Instead of stirred, sealed reactors as used for sludge digestion, upflow anaerobic filters generally are used. Filters may be packed with a support medium for anaerobic microorganisms to become attached or use a configuration which encourages formation of a high density floating sludge blanket. During the residence in the reactor, solids and complex organic materials in the waste are broken down to organic acids

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and alcohols. These acids are then biologically converted to methane and carbon dioxide, which may be withdrawn as a gas. The methane may be used on-site, or sold as fuel. A portion of the methane may be used to maintain the reactor at elevated temperatures.

Process Applications

Biological treatment has been applied successfully to a wide variety of aqueous waste streams with organic contaminants.

Trickling filters have been used by many municipalities for the treatment of domestic wastewater. In addition they are regarded as especially suitable for the treatment of high strength wastes prior to other biological or physical-chemical processes. They have been used extensively in the treatment of cannery, pharmaceutical, and petrochemical wastes. Treatment of refinery wastewaters containing oil, phenol and sulfide is a common application.

The activated sludge process has been used extensively in municipal wastewater treatment. Industrial applications include treatment of wastes from canneries, breweries, pulp and paper mills, petrochemical plants, refineries, textile mills, steel mills, and pharmauceutical plants.

Lagoons have been utilized to treat the same categories of waste streams and organic species as the activated sludge process.

Anaerobic processes have been used in the treatment of high-strength organic wastes, municipal wastewater sludges, and agricultural and municipal solid wastes. The broadest application has been for the treatment of sludges generated in the treatment of municipal sewage. Recently the anaerobic filter process or modifications of the process have been used to treat pharmaceutical, petrochemical, coal gasification, and other organic wastes. Full and laboratory scale studies using industrial wastes have examined a broad range of operating conditions; organic loading rates have ranged from 240 to 4000 kg COD/M^3/day (15 to 250 lb COD/1000 ft^3/day) and empty bed liquid retention times have ranged from 0.33 to 14 days. While anaerobic digestors commonly are heated to 35°C, or above, to increase the rate of biological decomposition, researchers have reported minimal temperature influence on anaerobic filter performance in the 10° to 30°C range.

Process Potential

Biological processes are, in general, the most cost-effective techniques for treating aqueous waste streams containing organic constituents. Moreover, biological processes have been

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applied successfully at full scale to a wide variety of industrial wastes. Environmental impacts associated with biological processes are limited. Probably of greatest concern in this regard is the potential release of volatile organic compounds to the atmosphere as a result of aeration.

For biological decomposition of organic materials of a hazardous nature, many of which are toxic to microbial flora at high concentrations, it is necessary that the system be allowed to acclimate to the waste to be treated prior to routine operation of the process.

The activated sludge process, in one of its modifications, appears to have the greatest potential for the application of interest because it can be controlled to the greatest extent and best lends itself to the development of an acclimated culture. However, anaerobic filtration because of ease of operation, minimal sludge production, and energy efficiencies merits consideration in many situations. Thus, biological treatment is judged to be a viable technology which must be considered for treatment of hazardous aqueous wastes containing organic constituents.

CARBON ADSORPTION

Process Description

Activated carbon removes materials from water by the process of adsorption. Since adsorption is a surface phenomenon, the very large surface area associated with activated carbon, typically 500-1400 m^2/g, makes it a very effective adsorbent.

Pores, created during the activation process, exist throughout the carbon particles and account for the very high surface-to-size ratio. The greatest portion of this surface area is contributed by pores of molecular dimensions. Thus, pore structure in addition to surface area is a major factor in the adsorption process. Pore size distribution defines the size distribution of molecules which can enter the carbon particle to be adsorbed. Therefore, the carbon adsorption process is dependent upon the physical characteristics of the carbon and the molecular size of the adsorbate.

For the most part, activated carbon surfaces are non-polar in nature. Thus, activated carbon will sorb most organic compounds to some extent but is most effective for the least polar and least soluble organic compounds. Inorganic electrolytes are not sorbed effectively.

Other factors which affect the adsorption process include the characteristics of the liquid phase (e.g., pH and temperature) and the contact time between the liquids and the carbon adsorbent.

The adsorption process is reversible which makes possible regeneration and reuse of activated carbons in many situations. Thermal regeneration is the most commonly used approach.

Activated carbon can be employed either in a granular or powdered state to effect treatment of wastewaters. Powdered carbon treatment usually involves suspension of the carbon in the wastewater in a stirred container and subsequent separation of the carbon-wastewater via a sedimentation process. Potential advantages associated with powdered activated carbon include:

- the cost of powdered carbon on a per pound basis is less than that of granular carbon,
- powdered carbon will equilibrate with the wastewater in a fraction of the time required by granular carbon,
- powdered carbon is easily slurried and transported, and can be supplied on demand by metering pumps,
- powdered carbon dosage can be rapidly changed to accomodate varying feed organic strength, and
- powdered carbon system requires a fraction of the carbon inventory required by granular carbon systems.

Development of powdered activated carbon technology has lagged behind that of granular carbon primarily as a result of lack of efficient regeneration systems. In addition, powdered activated carbon is sometimes difficult to separate from suspension and larger doses may be required than for granular systems achieving the same level of treatment.

Granular carbon applications are by far the more common. In this mode, the carbon is contained in a column or bed and the wastewater is passed through the contactor. After the capacity of the carbon bed is exhausted, the carbon may be removed and regenerated. Commonly, regeneration is accomplished by dewatering the carbon and then heating to a temperature of 815-925°C to volatilize and combust the adsorbed material.

One other treatment method involving the use of activated carbon exists. This technique involves the addition of powdered activated carbon to the mixed liquor in an activated sludge aeration basin to effect improvement in pollutant removal. Thus, this approach is a combined biological-carbon process. Regeneration of the carbon may be accomplished by thermal or wet oxidation techniques.

Process Applications

Activated carbon technology has been used for municipal water purification, municipal wastewater treatment, industrial wastewater treatment, sugar decolorization, and purification of fats, oils, foods, beverages and pharmaceuticals. Recently, activated carbon has been used successfully in several emergency hazardous material spill response operations.

Contaminants removed in municipal and industrial wastewater treatment operations include BOD, COD, TOC, color, chlorophenols, cresol, cyanide, insecticides, phenol, polyethers, polynitrophenol, p-nitrophenol, p-chlorobenzene, resorcinol, TNT, toluene, xylene, and other organic chemicals.

Process Potential

Activated carbon adsorption is a well developed technology which has a wide range of potential waste treatment applications. It is especially well suited for the removal of mixed organic contaminants from aqueous wastes. Numerous examples of full scale waste treatment applications exist.

No serious environmental impacts are associated with carbon systems employing regeneration. If regeneration is not carried out, impacts could result from the disposal of carbon contaminated with hazardous materials.

Energy requirements for systems employing thermal reactivation could be significant - approximately 14,000-18,600 kJ/kg of carbon (6,000-8,000 Btu per pound).

14,000 – 18,600 kJ/kg of carbon

Unit costs for carbon adsorption can vary widely depending upon the waste to be treated, the adsorption system, and the regeneration technique. It has been shown to be an economical approach in numerous instances.

In the current context, carbon adsorption must be considered a viable candidate for treatment of hazardous aqueous wastes containing organic contaminants. Granular activated carbon is the most well developed approach. However, combined biological-carbon systems appear promising for this application.

CATALYSIS

Process Description

A catalyst is an agent which accelerates the rate of a chemical reaction without itself being chemically altered at the end of the reaction. Catalysis, therefore, is not a process but rather is a means of enhancing any process which relies upon chemical transformations. In the current context, it is most applicable in improving the rate of chemical detoxification and degradation reactions. Thus, catalysis does not represent a means of concentrating wastewater constituents and is not considered a concentration technology.

Process Applications

Catalysts are used in a number of chemical reactions including oxidation, reduction, polymerization, hydration, dehydration, hydrolysis, isomerization, dehydrogenation, cracking, and others. Waste treatment applications have included:

- cyanide destruction with activated carbon and copper catalysts
- chlorinated organic pesticide destruction using metallic couples such as zinc/copper, iron/copper, and aluminum/copper; and pesticide dechlorination using nickel catalysts
- catalytic oxidation of domestic wastewater with proprietary catalysts and aqueous organic wastes with copper chromate catalyst
- oxidation of sulfides with iron and copper catalysts
- oxidation of aqueous phenolic wastes with Raney nickel catalysts and ferrous iron catalysts
- decomposition of sodium hypochlorite solutions with cobalt hydroxide catalyst
- isomerization of maleic acid into less water soluble fumaric acid with a hydrogen chloride or sulfuric acid catalyst.

Generally, catalysts are applied selectively based upon processes and pollutants of concern.

Costs of the catalyst are only a small part of the overall waste treatment process. Generally, the catalytic process permits lower temperature or pressure operation, therefore, capital and operating costs may actually be lower than the non-catalytic process. Costs are dependent upon the application with the only valid cost comparisons being between the catalyzed and non-catalyzed process.

Process Potential

Several potential applications of catalysis to waste treatment have been identified but commercial practicality has not been demonstrated.

Catalysts generally are very selective and, while potentially applicable to destruction or detoxification of a given component of a complex waste stream, do not have broad spectrum applicability.

In view of the above and the fact that catalysis is not a concentration technology, it was dropped from further consideration in this study.

CENTRIFUGATION

Process Description

Centrifugation involves the application of centrifugal force to effect mechanical solid-liquid or liquid-liquid separation via sedimentation or filtration within the centrifuge vessel. Several types of centrifuges are available - - tubular, disc, conveyor bowl, vertical basket, conical screen, and pusher to name a few. Raw wastewater or sludge characteristics such as particle size and solids concentration as well as desired product consistency should be considered when selecting the appropriate centrifuge.

Process Applications

Centrifugation as a solid/liquid separation process generally is used to process dilute sludges consisting of 2-5% solids. Typically, a dewatered sludge of 15-50% solids can be produced, although drier cakes are possible. Applications include:

- removal of particles and pigment from lacquers, enamels, and dye pastes
- separation of microorganisms from fermentation broths and solvent extracts from antibiotic broths
- recovery of metal particles from film soap and spent catalysts, and deoiling of metal chips
- recovery of crystalline solids from brine solutions, and ethylenediamine liquors and acrylonitrile wastewaters.
- dewatering of waste sludges e.g., domestic wastewater and scrubber sludges, separation of acid sludges from acid treatment of petroleum stocks
- removal of meat tissue from animal fats and pulp skins, and seeds in food processing
- dewatering of oil/water separator bottoms

Centrifugation also has been applied to separate liquids of different densities. Typical applications include:

- separation of oil and water mixtures;
- clarification of oils, extracts, and food products; and
- separation of wash water from fats and oils in vegetable and fish oil refining and purifying.

Centrifugation has greatest applicability for the dewatering of sludges and slurries. It cannot provide solids removal from aqueous waste sufficient for direct discharge of the centrate. The process has several advantages:

- demonstrated operation;
- versatile;
- compact, self-contained process;
- reasonable cost, low operating labor requirements;
- capable of dewatering problem sludges with minimal chemical modification;
- minimal secondary air pollution effects; and
- compatible with waste recovery

Disadvantages include:

- incomplete treatment of aqueous wastes;
- treatment of centrate may be difficult;
- a non-selective and non-destructive physical process; and
- possibility of high maintenance requirement when abrasive materials are processed.

Costs are comparable with other sludge dewatering alternatives such as vacuum and pressure filtration and in typical instances range from $22-50/tonne of dry solids ($20-45/ton).

Process Potential

$22-50/tonne of dry solids

Centrifugation is a viable ancillary process for sludge dewatering in an overall wastewater processing train. It may also have limited application for separating liquids of different densities. Because its chief application would be as an ancillary process to support some primary concentration technique, it was not evaluated in detail.

CHEMICAL PRECIPITATION

Process Description

Chemical precipitation is a process whereby some or all of a dissolved substance is transformed into a solid phase as the result of a chemical reaction and is thereby removed from solution. Most common precipitation reactions involve the removal of inorganic ionic species from aqueous solution.

Precipitation is accomplished in wastewater treatment by adding appropriate chemicals to the solution and mixing rapidly. Once the chemicals are dispersed throughout the solution, precipitation reactions generally are very rapid. However, the particles formed may remain very small in which case additional treatment will be necessary to promote particle growth (flocculation) prior to separation of the solid and liquid phases.

Typically precipitation is accomplished by the addition of lime, sodium hydroxide, aluminum salts, iron salts, carbonates, or soluble sulfides. In some instances, oxidation of the waste may result in the precipitation of the oxidized species (e.g., iron). Choice of the chemical to be used is dependent upon the nature of the waste stream and the material to be removed.

Process Applications

Precipitation techniques primarily have been used to remove metals and certain anionic species such as phosphates, sulfates, and fluorides. Numerous industrial applications exist. Examples include treatment of wastes from iron and steel mills, aluminum manufacturing, copper smelting and refining, metal finishing, and inorganic chemicals industry. Species reported to be removed by precipitation reactions include arsenic, cadmium, chromium, copper, fluoride, lead, manganese, mercury, and nickel.

Process Potential

Precipitation processes have been in full scale operation for many years. The technique can be applied to almost any liquid waste stream containing a precipitable hazardous constituent. Required equipment is commercially available. Associated costs are relatively low and thus, precipitation can be applied to relatively large volumes of liquid wastes. Energy consumption also is relatively low.

Precipitation processes result in the production of a wet sludge which must be further processed prior to ultimate disposal. In some instances, the potential for material recovery from this sludge exists. However, very often, non-target materials are precipitated together with the material of interest thus complicating or eliminating the feasibility of material recovery.

Usually, simple treatability studies must be carried out prior to applying the process to a waste stream to determine the chemical of choice, the degree of removal, and the required chemical dose.

In most instances, precipitation is considered to be the technique of choice for removal of heavy metals from aqueous hazardous wastes.

CRYSTALLIZATION

Process Description

Freeze crystallization is a technique which involves freezing an aqueous solution containing dissolved salts. Relatively pure ice crystals form and the salts are concentrated in the remaining brine solution. Ice crystals are mechanically separated from the brine, washed, and melted to yield fresh water. The remaining brine must be further treated or disposed of in some acceptable manner.

Basically, the process consists of: 1) heat exchange to cool the waste stream, 2) freezing using vacuum flash/vapor compression or secondary refrigerant freezing, 3) washing of the salts from the ice crystal, 4) melting of the ice to yield clean water, and 5) energy recovery to cool the incoming water and recover refrigerant. Major problems relate to the crystal/brine separation step and washing salt from the crystals. Also, because freeze point is influenced by waste stream composition, the process is very sensitive to fluctuations in waste stream composition. Difficulty has been experienced in making rapid operating adjustments to waste stream composition changes.

There are several claimed advantages to the process:

- because freezing is by direct contact with the refrigerant there is no heat transfer surface or membrane to be fouled
- at low temperatures, corrosion problems are minimized and less expensive materials can be used in construction
- volatiles can be separated from product water and condensed in the melting phase.

Process Applications

Demonstration scale testing of freeze crystallization has been carried out for desalination of seawater. However, only limited laboratory scale testing of the process on industrial wastes has been accomplished. There are no commercial applications of the process. Since AVCO Corporation's efforts in the mid-1970's there has been little or no research conducted.

Industrial wastes which have been tested include:

- cooling tower blowdown
- electronics plant waste
- ammonium nitrate wastes
- weak sulfuric acid wastes
- pulp mill hot caustic extract
- solutions of acetic acid, methanol, and aromatic acids
- metal plating rinsewaters
- arsenal redwater

Unsuccessful attempts also have been made to treat sludges at eutectic temperatures.

Experimental studies have utilized waste streams ranging from 0.003% to 10% TDS. Dissolved metal ions, cyanides, and organics theoretically are treatable provided that the waste stream has a component that freezes. Work has not been attempted on fully organic waste streams.

Energy requirements for desalination are high when compared to membrane processes but lower than evaporation processes, the two major competing desalination techniques.

Process Potential

AVCO Corporation has stated that the inability of the process to respond to changing wastewater characteristics and its operational complexity were primary reasons for abandoning its research efforts.

Since this process has not been reduced to practice, there is no ongoing research and past efforts have not been successful, this process was judged to have little potential for the application of interest and thus was dropped from further consideration.

DENSITY SEPARATION

In the current context, density separation is construed to include the process of sedimentation and flotation because they are the most commonly used techniques for solids/liquids separation in wastewater treatment.

Process Description

Sedimentation

Sedimentation is a physical process whereby suspended solids are separated from the liquid phase as a result of gravitational and inertial forces. Essentially, the technique consists of providing sufficient time and space for solid particles to settle out of a liquid stream. Usually, this is accomplished in special tanks, chambers or ponds designed to provide the necessary time and quiescent conditions to allow solids to settle. A means for physically removing the settled solids as a slurry or sludge usually is provided.

Although sedimentation processes may be batch or continuous, continuous processes are the most common in wastewater treatment applications.

Sedimentation frequently is used in conjunction with chemical precipitation, coagulation, and flocculation processes.

Flotation

The term flotation describes the process of converting suspended, colloidal or emulsified substances to floating matter. This may be brought about by the introduction of minute air bubbles into the liquid phase. These air bubbles attach to the solid particles and the buoyant force of the combination is sufficient to cause the particles to rise to the surface where they form a floating layer which is removed by skimming.

Air bubbles may be formed either by injecting air into the liquid waste under pressure with a subsequent release of pressure to atmospheric, or by saturating the waste with air at atmospheric pressure and then subjecting the waste to a vacuum which causes the release of dissolved air in the form of fine bubbles. Coagulant aids are sometimes added to the waste to assist the agglomeration of solids.

As a solids removal method flotation has several advantages:

- both light solids and greases, as well as heavy solids may be removed in the same apparatus,
- the sludge formed is usually more easily handled, and
- the presence of relatively high concentrations of oxygen in the waste helps promote the oxidation of organic components of the waste.

On the other hand, there are several attendant disadvantages of the process:

- both investment costs and operating costs are relatively high,
- because of the complexity of the equipment, maintenance costs are somewhat high, and
- the pressure type has high power requirements.

Process Applications

Sedimentation

Sedimentation has a long history of use in many applications. It is widely used in municipal and industrial water purification and wastewater treatment operations. Sedimentation is used in conjunction with chemical precipitation in all of the applications discussed under that topic.

Flotation

Flotation has been used successfully in the treatment of refinery wastes, food processing wastes, meat packing wastes, and paper manufacturing wastes. In general, its greatest application is to wastes containing oil or grease.

Process Potential

Sedimentation

Sedimentation processes have been in use for many years, are easy to operate, are low cost, and consume little energy. Required equipment is relatively simple and commercially available. The process can be applied to almost any liquid waste stream containing settleable material. It is considered to have high potential for the application of interest. However, it is an ancillary process which will be utilized primarily in conjunction with some other concentration technique such as chemical precipitation. Alternatively, it may be used as a pretreatment technique prior to another process such as carbon or resin adsorption.

Flotation

Flotation is a proven solids/liquids separation technique for certain industrial applications. It is characterized by higher operating costs and more skilled maintenance requirements than gravity sedimentation. Power requirements also are higher. This technique is judged to be potentially applicable but probably only in situations where the wastewater contains high concentrations of oil and grease.

DIALYSIS AND ELECTRODIALYSIS

Process Description

Dialysis is the transfer of small solute molecules in a waste stream through a semipermeable membrane into a wash stream flowing along the opposite side of the membrane. The transfer is driven by the concentration gradient between feed stream and wash stream. Factors controlling diffusion include membrane characteristics, membrane area, concentration gradient, and temperature. Membranes are capable of passing salts and small organic species while retaining colloids and higher molecular weight compounds. Dialysis treatment produces two output streams both being more dilute than the feed stream. The dialysate (treated feed stream) generally still will contain a higher concentration of solute than the diffusate (resulting wash stream). Thus, the process is of value in wastewater treatment if the dialysate or diffusate can be recovered and reused. The process does not provide volume reduction.

Membranes may be tubular, flat sheets, or hollow fiber configurations of cellulosic or synthetic resin materials. Membrane evaluation factors include transfer rate, mechanical strength, durability, resistance to chemical degradation, thermal stability and cost.

Electrodialysis is similar to dialysis, however, a direct electric current is the driving force causing charged ions to pass through or be rejected by membranes which are either anion or cation permeable. Staging or alternate stacking of anion and cation permeable membranes separated by spacers results in feed stream separations into dilute and concentrated streams. By concentrating salts in the brine stream, the process provides volume reduction. Membranes are formulated of synthetic ion exchange resins cast or copolymerized in sheet form.

Process Applications

For dialysis to work, the concentration gradient must be large; therefore, the process is applicable only to waste streams with high concentrations of low molecular weight dissolved species. Caustics and mineral acids dialyze readily; however, to minimize potential membrane degradation, the membrane must be carefully selected. Industrial waste treatment applications have included separation of caustic soda from hemicellulose waste, separation of soluble impurities from spent acid electrolyte in electrolytic copper refining, recovery of sulfuric acid in several industries, and separation of salts from proteins and other biocolloids in pharmaceutical manufacturing.

The process has several disadvantages in hazardous waste treatment including the need for pretreatment to minimize plugging, membrane erosion, and film or sludge formation on membrane surfaces; a low transfer rate; applicability only to concentrated waste streams; and generation of two dilute output streams.

Electrodialysis is applicable to aqueous wastes containing moderately high concentrations of inorganic salts (1000-5000 mg/l). The process can yield a brine stream containing up to 10,000 mg/l salt and a product stream of 100-500 mg/l salt. The most frequent application has been production of potable water from brackish water. It also has been used to concentrate seawater for salt production; to remove mineral constituents from organic process streams, e.g., the desalting of whey, de-ashing of sugars, and washing of photographic emulsions. Laboratory and pilot scale applications include treatment of secondary sewage effluent, acid mine drainage, demineralization of cooling waters, and treatment of plating liquors and rinses to salvage metals and acids.

An advantage of electrodialysis is that costs are moderate, but they are heavily dependent upon volume treated and amount of salt removed because of the fixed removal capabilities of a given stack of membranes. The process, however, has a limited range of applicability in terms of wastewater salts concentration and types of solutes which can be concentrated.

Process Potential

Neither process has been judged to have much applicability to aqueous hazardous waste treatment in the current context. They are not well suited to mixed constituent waste streams and both rely heavily on recovery and reuse of at least one product stream to offset costs. Dialysis should not be considered to be a concentration technology. Neither process was evaluated further.

DISTILLATION

Process Description

Distillation may be carried out in a variety of ways but usually involves boiling a mixture of liquids to produce a vapor that is rich in the lower boiling point components of the original mixture. The vapor may be condensed and recovered or recycled in part to the distillation system. Distillation can be carried out in a series of stages which in the limit can approach a complete separation of the components.

Distillation is expensive and energy intensive. It probably can be justified only in cases where valuable product recovery is feasible.

TYPING GUIDE SHEET

Process Applications

Distillation has wide industrial application in petroleum refining, organic chemical manufacture and purification, and solvent recovery. Treatment of waste by distillation is limited. The only hazardous waste materials which feasibly can be treated are liquid organics such as organic solvents and halogenated organics. Some specialized applications include:

- waste oil re-refining,
- methylene chloride recovery,
- ethylbenzene separation from styrene, and
- waste solvent recovery.

Process Potential

Distillation is judged to have limited applicability to treatment of dilute aqueous hazardous wastes because of its high cost and energy requirements. Therefore, it has been dropped from further consideration.

EVAPORATION

Process Description

Evaporation is the process of vaporization of a liquid from a solution or slurry as the result of application of heat energy. It is applied in situations where one of the components of the system is not appreciably volatile. Products of evaporation are a relatively pure condensed solvent and a concentrate rich in the nonvolatile component.

Evaporation differs from distillation in that the vapor usually is a single component and even when it contains more than one component, no attempt is made to fractionate the vapor.

Usually, heat is supplied by condensing steam in a heat exchanger that is an integral part of the evaporation unit. Commonly, evaporation units are operated under some degree of vacuum to reduce the boiling temperature. Evaporation often is carried out in a series of stages or effects. Since large quantities of vapor are produced, it often is economically advantageous to use the vapor produced in one stage as the heating medium for a subsequent stage. Thus, multiple effect evaporation often is practiced.

Evaporation, usually, is not econmically feasible for solutions having a low solids content. Equipment costs are high and operating costs may become excessive for the concentration of very dilute solutions. Potential operational problems include salt buildup on heat exchange surfaces, foaming, and solids decomposition.

Process Applications

Evaporation is a proven, well-developed process which is utilized in some form by virtually every industry. Waste treatment applications include radioactive wastes, TNT wastes, photographic chemical dye wastes, paper mill wastes, molasses distillery wastes, and metal plating wastes. Often product recovery is associated with industrial waste treatment schemes which employ evaporation.

Process Potential

Evaporation is not expected to have broad application to the treatment of aqueous hazardous wastes containing moderately volatile organic constituents (BP 100°C-300°C). These organics cannot be easily separated in a pretreatment stripper and will appear in the condensate from the evaporator to some extent depending on their volatility. Therefore, good clean separation of these organics is not possible without post-treatment of the condensate.

The major disadvantages of evaporation are high capital and operating costs, and high energy requirements. This process is more adaptable to wastewaters with high concentrations of pollutants than to wastewaters with low concentrations of pollutants.

In view of the above, evaporation was dropped from further consideration for the application of interest.

FILTRATION

Process Description

Filtration is a process for separation of solids from fluids by passage of the fluids through a porous medium. The solids are retained by the filtering medium itself and/or by solids already trapped on the medium. The fluid may be gaseous or liquid but, in the current context, only liquid/solids separations are of interest.

Many types of commercially available filtration systems exist. An important factor in selection of the type of filtration system is the desired objective. If the intent is to produce a purified liquid stream, a different type of filtration system would be selected than if the objective was to concentrate the solids prior to subsequent processing or disposal.

Filtration systems may be classified according to the porous medium used. Generally used filter media fall into one of two classes: (1) granular media, and (2) flexible media.

Granular Media

Granular media filters usually consist of beds of sand or sand and coal within a basin or tank and supported by an underdrain system. Filtration is accomplished by passage of the waste stream through the bed. Through a complex process that may involve several mechanisms, particles are trapped on top of and within the bed. As this occurs, the porous nature of the bed is reduced thus, either reducing the filtration rate at constant pressure or increasing the amount of pressure required to maintain the filtration rate. At some point the filter must be removed from service and backwashed to scour the solids from the media. The spent backwash water containing the suspended solids must be collected and further treated or disposed in some manner.

Granular media filters primarily are used to produce a high quality water low in suspended solids. These systems cannot effectively filter liquids having high suspended solids concentrations because backwash frequently becomes excessive.

Flexible Media

Flexible media filters are characterized by the flow of a waste stream through a fine medium such as cloth or close mesh screen. Solids build up on the medium as a cake which then serves as the true medium for further filtration.

The flow through filters of this type is induced by a pressure difference across the filter media. One type of filter commonly used in the chemical industry is the plate-and-frame filter which consists of alternating hollow frames that serve to contain the retained filter cake. Pressed against this frame are plates which support the filter cloth and which are provided with drainage channels for carrying off the liquid filtrate. When the frames are completely filled with cake, the plates and frames are separated and the cake removed.

Leaf filters consist of cloth supported on thin hollow grids stacked in a cylindrical pressure vessel. Liquid filtrate passes through the cloth and is discharged through passages in the leaf units.

Several types of continuous filters are available which have the advantage of requiring much less labor for operation. Basically they involve the use of a rotating hollow drum covered with filter cloth supported by a screen backing. As the drum slowly rotates on its horizontal axis, the lower segments of the drum dip into a tank containing the slurry to be filtered. The piping is arranged so that a vacuum can be applied in the immersed section of the drum from the inside pulling the filtrate into the section and leaving cake on the outer surface of the drum. The vacuum will produce a partial dewatering of the cake.

At a suitable point in the drum rotation, the cake is scraped from the drum. Filter aids are sometimes added to the slurry to improve the filterability, provided that recovery of uncontaminated solids is not the prime objective of the operation.

These types of filters primarily are used for dewatering sludges rather than for producing a purified liquid.

Process Applications

Filtration is a process with a long history of use in numerous industrial processes, and municipal and industrial water and wastewater treatment operations. Often filtration is used in conjunction with precipitation, flocculation, and sedimentation processes to effect improved solids removal efficiency.

Filtration has been used as a polishing step following precipitation and sedimentation to remove arsenic, cadmium, chromium, lead, nickel, and zinc.

As a dewatering technique, filtration has been utilized extensively to dewater biological and chemical wastewater treatment sludges.

Process Potential

Filtration is a well developed process currently being used in a wide variety of applications. A wide spectrum of filtration systems are commercially available. The economics of filtration are reasonable for many applications. Energy requirements are relatively low and operational parameters are well defined. Therefore, filtration is judged to be a good candidate for the application of interest. However, it is not a primary treatment process but rather will be used to support other processes either as a polishing step subsequent to precipitation and sedimentation or as a dewatering process for sludges generated in other processes.

FLOCCULATION

Process Description

Flocculation, as used herein, is the process by which small particles suspended in a liquid are made to aggregate into larger particles which are more readily settled. Generally, flocculation is accomplished by the addition of chemicals to the suspension under a high degree of turbulence to effect rapid and thorough mixing. This rapid mixing is followed by a period of gentle stirring to promote particle growth.

Flocculating chemicals include alum, lime, iron salts, and organic polymers (polyelectrolytes). The inorganic flocculants react to form large, fluffy precipitates or floc particles which act to enmesh small particles creating larger, more settleable particles.

Flocculation may be employed in situations where it is desired to remove suspended solids originally present in the wastewater or solids formed in a preceding precipitation process. For example, sulfide precipitation of some metals results in the formation of a relatively stable colloidal suspension. Alum and/or polyelectrolytes can be used to effect flocculation of the metal sulfide precipitates.

Flocculation usually is used in conjunction with precipitation and sedimentation. Indeed, many of the inorganic flocculants make use of precipitation reactions. Once the precipitate has been formed and the suspended particles have been flocculated, they can be separated from the liquid by sedimentation.

Process Applications

Flocculation has a long history of use in numerous municipal and industrial water and wastewater treatment applications. It has been used in conjunction with precipitation to remove arsenic, cadmium, calcium, chromium, copper, lead, magnesium, mercury, and nickel. In addition, it is used in in many water and wastewater treatment systems to remove suspended solids. Inasmuch as many pollutants such as pesticides and PCBs are often adsorbed to particulate matter in suspension, flocculation in conjunction with sedimentation can result in the removal of the associated pollutants.

Process Potential

Flocculation is a relatively simple process to operate and has been in use for many years. Necessary equipment is commercially available. Both costs and energy consumption are relatively low. The process can be applied to almost any aqueous waste stream containing precipitable and/or suspended material.

Flocculation must be carried out in conjunction with a solid/liquid separation process, ususally sedimentation. Often, flocculation is preceded by precipitation.

Flocculation is judged to be a viable candidate process for hazardous aqueous waste treatment, particularly where suspended solids and/or heavy metal removal is an objective. It may be used in conjunction with sedimentation as a pretreatment step prior to a subsequent process such as activated carbon adsorption.

In most instances, the applicability of the technique, the flocculating chemicals to be used, and the chemical dose can be judged based upon experience and simple laboratory treatability tests.

ION EXCHANGE

Process Description

Ion exchange involves a reversible interchange of ions between an insoluble, solid salt (ion exchanger) and a solution of electrolyte in contact with the ion exchanger. Thus, in an ion exchange process, certain ionic species are removed from solution and replaced by ions of the same sign which are released from the exchange matrix.

Ion exchange materials may be natural minerals or zeolites, or may be snythetic substances specially prepared for specific properties. They generally contain a large number of soluble ionic functional groups at the surface. At these locations, the ion exchange reaction occurs. It is possible to alter selectivity of these materials towards inorganic and organic materials by altering the physical and chemical characteristics of the exchangers.

Commonly, ion exchange media are contained in columns or beds. Liquid which is relatively free of suspended solids is passed through the beds until the effluent concentration of the material which is being removed exceeds a desired value. At that point the exchanger must be regenerated. This is accomplished by passing a regenerant solution containing a high concentration of the ion originally associated with the exchanger through the bed. The exchanger thus is converted back to its original form and the pollutant, at elevated concentrations, is transferred to the regenerant solution. Used regenerant must be recovered for reuse by additional processing or disposed of in an acceptable manner. Usually, the bed is rinsed with a small volume of water to remove excess regenerant prior to the next service cycle.

Process Applications

Ion exchange can be used to remove both cations and anions. Because organic species frequently interact with the exchangers and cause operational problems, most applications of interest in the current context have involved inorganic species.

The ion exchange process has been used for many years to soften water. It also has a long history of use in industrial water purification.

Ion exchange is used extensively in the electroplating industry for treatment of rinse waters containing chromium, cyanide, and nickel. It also has been used as a polishing step in processes designed to treat aqueous metal finishing wastes.

Other applications include:

- removal of iron, aluminum, and chromium III from chromic acid plating bath liquors,
- removal of aluminum from strong phosphoric acid/nitric acid solution,
- removal of various species from radioactive wastes, and
- removal of ammonia from biologically treated municipal wastewater.

Process Potential

Ion exchange is a proven process with a long history of use. It will remove dissolved salts, primarily inorganics, from aqueous solutions. For many applications, particularly where product recovery is possible, ion exchange is a relatively economical process. Also, it is characterized by low energy requirements.

Ion exchange is judged to have some potential for the application of interest in situations where it is necessary to remove dissolved inorganic species. However, other competing processes - precipitation, flocculation, and sedimentation - are more broadly applicable to mixed waste streams containing suspended solids, and a spectrum of organic and inorganic species. These competing processes also usually are more economical. Thus, the use of ion exchange probably would be limited to situations where a polishing step was required to remove an inorganic constituent which could not be reduced to satisfactory levels by preceding treatment processes. Therefore, while ion exchange is believed to have some potential for the current application, it is not a process which should receive primary consideration.

RESIN ADSORPTION

Process Description

Resin adsorption functions according to the same principles associated with carbon adsorption. That is, physical and chemical forces cause sorption of the solute onto the resin's surface. A major difference between resin and carbon adsorption is that because adsorption forces are weaker, resins can be chemically rather than thermally regenerated. This provides an opportunity to recover sorbed materials. Another difference is that, while activated carbon sorbs nonpolar compounds most readily, resin surfaces can be produced to be either hydrophobic or hydrophilic and thus be applicable to nonpolar or polar molecules.

Two basic types of synthetic resin adsorbents are available, polymeric and the newer carbonaceous. The polymeric adsorbents are nonpolar with an affinity for nonpolar solutes in polar solvents or of intermediate polarity capable of sorbing nonpolar solutes from polar solvents and polar solutes from nonpolar solvents. Carbonaceous resins have a chemical composition which is intermediate between polymeric adsorbents and activated carbon and are available in a range of surface polarities. As with activated carbon, pore size distribution and surface area affect the sorption process. These characteristics vary for the different resins. Surface areas range from 100-700 m^2/g, generally less than activated carbon.

Resins are used in manner comparable to granular activated carbon, i.e. in beds or columns with wastewater passed through the contactor. After sorbent capacity has been exhausted, spent sorbents generally are regenerated by steam, acid, caustic, or organic solvent (methanol, ethanol, acetone - - although it is highly flammable, isopropanol, and others) washing. Subsequent separation of the desorbed solute from the wash stream permits recovery of the solute. Credit for solute recovery may offset the severalfold higher initial cost of resins relative to carbon. Chemical regeneration also minimizes scale problems when waste streams high in inorganic solids are treated. It is claimed that resins, especially carbonaceous resins, have longer service lives than carbon because of greater resistance to attrition.

Process Applications

Resin sorption technology is not as well developed as carbon sorption and therefore, process applications are more limited. One application which has been examined is the treatment of munitions wastewaters primarily because solvent rather than thermal regeneration was more desirable. Other applications have included color removal from paper mill bleach effluents, dyestuff production plants, water supplies, and in the food and pharmaceutical industries; phenol removal and recovery; pesticide manufacture wastewater treatment; removal of organics in the production of ultra-pure water; removal of chlorinated hydrocarbons in vinyl chloride manufacturing; and removal of chlorinated hydrocarbons from contaminated groundwater. Laboratory studies have shown that phthalate esters, aldehydes and ketones, alcohols, chlorinated aromatics, aromatics, esters, amines, chlorinated alkanes and alkenes, and pesticides are adsorbable by resins. Resins adsorbed certain amines and aromatics better than activated carbon did.

Resin adsorption has greatest applicability when:

- color due to organic molecules must be removed
- when solute recovery is practical or thermal regeneration is not practical

- where selective adsorption is desired
- where low leakages are required
- where wastewaters contain high levels of dissolved inorganics

Process Potential

Because of selectivity, rapid adsorption kinetics, and chemical regenerability, resins have a wide range of potential applications. The primary disadvantage is high initial cost; although, this may be offset if recovery of the solute is practical. Costs for resins recently have been quoted to be $11-33 per kg ($5-15 per pound). While not economically competitive with carbon for high volume, high concentration, mixed constituent wastes, benefits may be gained by sequential resin and carbon adsorption.

Energy requirements are heavily dependent upon whether solute recovery from the wash media is practiced. Without solute recovery, energy costs account for 5% of operating costs; however, with solute recovery using distillation, energy costs could account for 50% of operating costs.

As with activated carbon, the only major environmental impacts relate to the regeneration process. If not reused, spent regenerant requires disposal, frequently by incineration or land disposal.

Resin sorption has been judged to be a viable candidate for treatment of hazardous aqueous organic wastes. The technology, however, has not been as well defined as carbon adsorption.

REVERSE OSMOSIS

Process Description

Reverse osmosis (RO) is a salt removal process which has been intensively developed over the past 15 years for treatment of both brackish water supplies and wastewaters.

A natural phenomenon known as osmosis occurs when solutions of two different concentrations are separated by a semi-permeable membrane such as cellophane. Water tends to pass through a semipermeable membrane from the more dilute side to the more concentrated side, thus producing equal dissolved solids concentrations on both sides of the membrane. The ideal osmotic membrane permits passage of water molecules but prevents passage of ions such as sodium and chloride. For example, if a solution of sodium chloride in water is separated from pure water by means of a semi-permeable membrane, water will pass through the membrane in both directions, but it will pass more rapidly in the direction of the salt solution. At equilibrium, the quantity of water passing in either direction is equal, and the pressure is defined as the osmotic pressure of the solution having that particular concentration of dissolved solids.

The magnitude of the osmotic pressure depends on the concentration of the salt solution and its temperature. By exerting pressure on the salt solution, the osmosis process can be reversed. When the pressure on the salt solution is greater than the osmotic pressure, fresh waster diffuses through the membrane in the opposite direction to normal osmotic flow--hence the name for the process, reverse osmosis.

Many materials have been studied for possible use as membranes for water and wastewater purification and related separation and concentration procedures. The most widely used membrane developed to date is simply a modified cellulose acetate film. Polyamide materials and polyarylsulfones are more recent developments.

The semi-permeable membrane acts to retain the ions such as sodium and chloride on the brackish water side, while permitting pure or nearly pure water to pass through the membrane. The properties of a membrane that permit water molecules to pass through but will not permit the flow of salt ions are not clearly understood. It is believed not to be simply a molecular filtering action even though individual water molecules are smaller than most of the ions of concern.

The water flux through the membrane is dependent upon the applied pressure, while the salt flux is not. As the pressure of the feed water is increased, the flow of water through the membrane should increase while the flow of salt remains essentially constant. It follows that both the quantity and the quality of the product water should increase with increased driving pressure.

Operating plants carry out the reverse osmosis principle in several different process designs and types of membrane configurations. There are four types of membrane systems which have been used:

1. spiral wound,
2. hollow fine fiber,
3. tubular, and
4. plate and frame module.

The first three types are in commercial production and are currently in use in operating plants. The plate and frame approach is not an efficient use of membrane surface area.

Membranes are susceptible to chemical attack and fouling, and the flow systems are susceptible to plugging and erosion. Therefore, it is common to preprocess feed water to remove oxidizing materials, oils, greases, and particulates. Typical pretreatments include carbon adsorption, chlorination, pH control, and filtration as dictated by the nature of the feed water. Cellulose acetate membranes are typically operated at pressures of 2760-4140 kN/m^2 (400-600 psi) to produce flux rates of 0.204-0.815 $m^3/m^2.d$ (5-20 $gal/day/ft^2$).

Process Applications

Probably the most extensive use of reverse osmosis to date has been in the production of purified water from brackish or seawater. Other applications include preparation of rinse water for use in semiconductor and electronic manufacturing, and reclamation of chemicals and water from electroplating rinse waters. To a limited extent reverse osmosis has been used in treatment of sulfite pulping wastes, textile dying wastes, and pharmaceutical wastes.

Process Potential

Reverse osmosis is a relatively new process which has been reduced to practice for some applications. A number of competitive suppliers of reverse osmosis systems exist. Energy requirements for commercially available systems are about 7.61×10^6 - 9.51×10^6 J/m^3 of product water (8-10 kwh/1000 gal). Reverse osmosis is a relatively costly process but it is capable of producing high purity water. The principal application is to concentration of dilute solutions of inorganic and some organic solutes.

The state of development of the process is such that it is necessary to conduct extensive bench and pilot scale testing prior to almost any potential application to ascertain feasibility.

Reverse osmosis in its present state of development is judged to have limited potential for the application of interest. Its use probably will be limited to polishing operations subsequent to other more conventional processes.

SOLVENT EXTRACTION

Process Description

Solvent extraction as used herein is the separation of constituents of a liquid solution by contact with a solvent that is immiscible with the liquid. Components of the original solution are transferred to the solvent for subsequent recovery or removal. Recovery and reuse of the solvent usually is dictated by economics. Unless the solvent has very low solubility in the original liquid, there will be solvent loss which, in addition to increasing process cost, may cause unacceptable contamination.

A solvent extraction process usually involves effecting intimate contact between the feed and solvent phases by forced mixing or by countercurrent flow. Subsequent to mixing the two phases are separated and the solute is removed from the solvent by distillation, a second solvent extraction step, or some other technique. Solvent recovery from the treated feed stream also may be dictated by economics or discharge requirements.

Process Applications

The use of solvent extraction is limited. Commercial applications include manufacture of lubrication oil from crude oil, upgrading of gasoline, extraction of sulfur compounds from gasoline, refining vegetable oils and fats, and dehydration of acetic acid. The principal wastewater treatment application is removal of phenol and related compounds from petroleum refinery wastes, coke-oven liquors, and phenol resin plant effluents.

Process Potential

Solvent extraction is judged to have minimal potential for the application of interest. Broad spectrum sorbents such as activated carbon are expected to be more effective in treating dilute waste streams containing a diversity of organic compounds. Carbon adsorption also will be more economical unless a valuable product can be recovered which is unlikely in most cases expected to be encountered. Therefore, solvent extraction was dropped from further consideration.

STRIPPING

Process Description

Two types of stripping are possible: air and steam. Air stripping involves the passage of air through an aqueous stream to remove a volatile component. Steam stripping essentially is a fractional distillation of volatile compounds from a wastewater stream.

Although air stripping from tanks and ponds is possible, usually this process is carried out in packed towers. Typically, the liquid stream is introduced at the top of a packed tower and air is forced through the tower countercurrent to the liquid flow. Depending upon the component to be removed, both temperature and pH may be important variables in determining process effectiveness and efficiency. Air pollution control devices will be required unless it can be shown that direct emission of the air stream to the atmosphere has no adverse environmental impact.

Steam stripping usually is carried out in a packed tower or conventional fractional distillation column with more than one stage of vapor/liquid contact. Preheated wastewater is introduced near the top of the column and flows countercurrent to the steam rising from the bottom of the column. The concentration of the volatile component in the liquid progressively decreases as the liquid passes down through the column. Wastewater at the bottom of the column is heated by the incoming steam. Heat recovered from the wastewater discharged from the bottom of the column is used to preheat the incoming feed.

Steam exiting the column is condensed and must be further processed for product recovery or disposed in an acceptable manner. Recycle of a portion of the condensed vapor to the stripping tower may or may not be practiced.

Process Applications

The only major application of air stripping is the removal of ammonia from domestic wastewater.

Steam stripping has been used primarily for ammonia, hydrogen sulfide and phenol removal from aqueous streams. Ammonia is removed by steam stripping for product recovery from coke oven gas scrubber water. Other recovery operations involving steam stripping include sulfur from refinery sour water and phenol from phenol production process water. Industrial waste treatment applications which have been reported include:

- phenol removal from phenol plant effluent
- removal of vinyl chloride monomer from suspension resins of polyvinyl chloride
- removal of methanol and sulfur compounds from Kraft mill condensates

Process Potential

Air stripping is judged to have minimal potential for the application of interest. The process would be difficult to optimize for hazardous aqueous waste streams containing a spectrum of volatile and non-volatile compounds. Air stripping does have appeal as a pretreatment prior to another process such as adsorption to extend the life of the sorbent by removing sorbable organic constituents. However, air pollution control requirements are likely to be severe thus making the economics less attractive. It should be noted that some air stripping of volatile components will occur during the course of any treatment process and may result in safety hazards or air quality problems. This is expected to be most severe in the case of biological treatment processes using aeration devices.

Steam stripping has merit for wastes containing high concentrations of highly volatile compounds. It is a proven process for some applications but will require laboratory and bench scale investigations prior to application to waste streams containing multiple organic compounds. Both energy requirements and costs are relatively high. By-product recovery to offset costs from the types of hazardous waste streams under consideration is unlikely.

For the application of interest, steam stripping is judged to have greatest potential as a pretreatment step to reduce the load of volatile compounds to a subsequent treatment process.

ULTRAFILTRATION

Process Description

Ultrafiltration as a method for removal of contaminants in wastewater is one of a number of processes employing semi-permeable membranes. Ultrafiltration differs from reverse osmosis in that ultrafiltration is not impeded by osmotic pressure and can be effected at low pressure differences of 34.5 to 1380 kN/m^2 (5 to 200 psi).

34.5 to 1380 kN/m^2

Ultrafiltration usually is applicable for separation of higher molecular weight (7500) organic materials ranging in size from about 100 angstroms upwards. The upper molecular weight limit for ultrafiltration is usually near 500,000. Above that molecular weight size, separation occurs by conventional microporous filtration.

The predominant mechanism in membrane ultrafiltration is selective sieving through pores of the membrane. Membrane rejection of a certain substance depends upon its molecular shape, size and flexibility as well as the operating conditions. A useful membrane must be able to effect separation distinctly at an economical flow rate.

Polycarbonate resins, substituted olefins and polyelectrolytic complexes have been employed among other polymers to form ultrafiltration membranes. Most ultrafiltration membranes on the market today are cellulose acetate or derivatives therefrom. This imposes some limitations on use. The pH range of the liquid must be between 4 and 9 and operating temperatures are restricted to less than 43°C to avoid hydrolysis of the cellulose acetate. Polyarysulfones and inorganic materials have been introduced to deal with high temperatures and pH values.

Typical membranes used in wastewater treatment are composed of an extremely thin surface layer or skin covering a porous substructure of the same material. The porous substrate is required for mechanical strength. Many times the membranes are reinforced with a nonwoven material such as paper to give added mechanical strength.

A variety of configurations are available for use of these membranes in the ultrafiltration of wastewater. These include tubular units, plate and frame units, and spiral wound units. Most ultrafiltration systems are designed with similar flow patterns. A series-parallel layout is employed in which the dilute waste stream passes through several parallel membrane blocks or housings. This concept was developed to avoid the fouling inherent in direct onflowing systems. The typical design involves flow across the membrane face instead of directly onto it.

Ultrafiltration generally operates at lower total throughputs and considerably higher solute concentrations than reverse osmosis.

Process Applications

Ultrafiltration has been used primarily in small laboratory and industrial applications for product recovery or production of a highly purified solvent. Primary commercial applications of ultrafiltration include:

- electropaint paint rejuvenation and rinse water recovery,
- protein recovery from cheese whey,
- metal machining oil emulsion treatment,
- textile sizing (PVA) waste treatment, and
- sterile water production for pharmaceuticals manufacturing.

Potential applications under development include dye waste treatment, pulp mill waste treatment, industrial laundry waste treatment, protein recovery from soy whey, and hot alkaline cleaner treatment.

Process Potential

Ultrafiltration is a commercially used process with several industrial applications. It is characterized by high capital and operating costs. Energy costs could run as high as 30% of direct operating costs.

Ultrafiltration is judged to have limited potential for the application of interest. Its use probably would be limited to relatively low volume streams containing substantial quantities of high molecular weight solutes or suspended materials. Pilot testing is a prerequisite to use.

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SECTION 7

LITERATURE REVIEW

DESCRIPTION

This section describes and summarizes an extensive literature review which was undertaken as the second step in the technology screening process. In order to provide a consistent and coherent basis for comparing and evaluating various processes, a standard format was used to record data and observations gleaned from the literature:

- (1) Keywords
- (2) Reference (Literature Citation)
- (3) General Description
- (4) Organization and Location
- (5) State of Development
    - (A) Type of operation
    - (B) Size of operation
    - (c) Duration and frequency of operation
- (6) Influent Waste Characteristics
- (7) Process Ranges
    - (A) Application
    - (B) Operation
    - (C) Constraints
    - (D) Other limitations
- (8) Operations
    - (A) Performance data for major parameters
    - (B) Equipment and supply requirements
    - (C) Energy requirements
    - (D) Flexibility
    - (E) Reliability
- (9) Effectiveness
    - (A) Effluent quality and efficiency
    - (B) Form of Material
- (10) Process Economics and Costs
- (11) Environmental Acceptability
- (12) Pilot Plant Operations

Special effort was made to adhere to this format as closely as prudent engineering and scientific judgment allowed. However, it became apparent early in the effort that limited information on full or even pilot scale application of many of these

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processes to hazardous aqueous streams existed. Rarely was information covering all the above items presented. This general absence of data was compounded by frequent reporting of technology performance using gross pollutant indicators such as COD or TOC rather than removal of specific pollutants.

Despite these problems, an extensive amount of pertinent literature was reviewed and summarized. In order to maximize the usefulness to the reader of the large quantity and wide diversity of information extracted from the literature, it is presented in several degrees of detail herein. The most detailed data summary is contained in Appendix C. Information in this Appendix is presented in a standarized tabular format arranged according to each candidate concentration technology. Data is further subdivided within each technology group on the basis of the previously described chemical classification system.

The second level of detail is presented in the form of a narrative literature summary and is contained in a subsequent portion of this report section. The organization of this summary description is similar to that of the tabular presentation contained in Appendix C. Primary emphasis has been placed on the ability of the several processes to treat chemical compounds in the various classes of interest. General descriptions of individual technologies are contained in the technology profiles and can be found in numerous standard texts. Rather than reiterate much of this basic information, this study instead builds upon it, expanding the discussion of technology application, especially treatment of specific chemical compounds.

The most concise summary of the literature information has been presented earlier in Table 1 which is arranged according to unit process and individual chemical. This is intended to provide quick reference on the treatability of a chemical by the various candidate processes. It also serves to illustrate information gaps. This table can serve as a tool in the decision making process to match a treatment process or processes with the waste stream of interest. Efforts to identify all potential processes thus would be greatly reduced. Evaluations and treatability studies, although probably still necessary, could be conducted in a less costly and time consuming manner. This is of special importance when actions must be taken rapidly to mitigate imminent hazards.

LITERATURE SUMMARY

The following summary has been prepared on the basis of information gained from the literature review and is arranged by concentration process. Additional details are contained in Appendix C.

Biological Treatment

A variety of biological processes are used for wastewater treatment. This review generally was limited to configurations of the activated sludge process, i.e., conventional, extended aeration, contact stabilization along with aerated lagoon treatment. Although not solely a concentration technology because pollutant degradation and transformation occur, chemicals are concentrated in and on the biomass via adsorption or metabolic processes.

Biological processes appear to be capable of treating numerous organic and inorganic pollutants, although only limited data on removal of hazardous compounds in full scale applications (56,81,100,101) are available. A report by Pajak, et al.(71) presents an extensive review of the effect of hazardous materials on biological treatment processes. Much of these data, however, reflect laboratory scale studies.

Alcohols

Removal of various alcohols by biological treatment generally was high even at concentrations up to 1000 mg/l. Several references on the activated sludge process reported reductions of 75-100% (56,81,101,133). Aerated lagoon treatment of alcohols achieved 38-85% reductions (100). Placak and Ruchhoft (103) stated that 24-38% of the removal resulted from oxidation and 52-66% by conversion into protoplasm. Several toxicity thresholds to sensitive aquatic organisms were presented by Lund (99).

Aliphatics

Biodegradation efficiency of aliphatics spanned a wide range. Bess and Conway (100) observed zero to complete removals for various aliphatics by aerated lagoon treatment. Several references reporting on the activated sludge process cited generally high performances (56,81,90,101). Biodegradation of many of the aliphatics was based upon respirometer tests, theoretical oxygen demands and toxicity thresholds (103,106,107,108,109,112).

Amines

Reported removal of amines was variable. Pitter (133) as reported by SCS Engineers (81) described several amines as readily biodegradable using acclimated activated sludge inocula. Melaney, *et al.* (107,108), however showed that many of these compounds, *e.g.*, benzamide, benzidine, benzylamine, 2-fluorenamine and others, inhibited oxygen consumption. Alternative systems utilizing mutant bacteria were reported to completely degrade aniline and trichloroaniline (92), although Melaney (108) indicated that aniline inhibited oxygen uptake. Leipzig and Hakenburg (58) reported 99.9% reductions of nitroaniline using powdered activated carbon in an activated sludge system.

Aromatics

Wide variation in the treatability of aromatics has been reported. Bess and Conway (100) reported 10-100% reductions by aerated lagoon treatment. Some aromatics, e.g., mono, di, tri, tetra, and hexachlorobenzenes, were completely degraded by pseudomonas bacteria (66,92). Leipzig and Hakenburg (58) reported up to 96% reductions of nitrobenzene using powdered activated carbon in an activated sludge process. Pure activated sludge performances ranged from 50-100% (56,81,90,101). Dryden, *et al.* (90), however, stated that the compounds of this group are fairly biorefractory. This is supported by reports on general toxicity or inhibitory effects (102,106,108,109). Dryden, *et al.* (90) further suggested that achievable reductions attributed to biodegradation may be attained by air stripping or adsorption on the biomass.

Ethers

References relating to ethers all pertained to isopropyl ether. Activated sludge processes achieved 85-95% reductions (56,101). Bess and Conway (100) reported 70-90% removals by aerated lagoon treatment.

Halocarbons

Halocarbons generally are reported as biorefractory and inhibitory to biological growth (90). Several references, however, reported effective removals by biological treatment at concentrations up to 1.3 mg/l (21,58,65). Although not stated, these reductions may be attributable to the volatile nature of these compounds. Dryden, _et al_. (90) reported that halocarbons may not be detrimental to an activated sludge system since they tend to air strip readily.

Metals

Metals frequently were reported to inhibit biological activity (71,109,124,127). A review by Pajak, _et al_. (71) reported that bimetallic mixtures often were more toxic than the individual metals. Toxicity thresholds, however, appear to exist for many metals, e.g., barium, cadmium, chromium, manganese, and zinc. Toxicity thresholds varied from metal to metal ranging from 1 to 100 mg/l. At concentrations less than these thresholds, biological activity occasionally was reported to be stimulated (109,124). Reductions of 30-80% often were reported at concentrations ranging from 0.006-10 mg/l (118,122,128,132).

Pesticides

Except for herbicide orange (81) and 2,4,5-trichlorophenoxyacetic acid (115), only slight biodegradation of pesticides was demonstrated (121). Wilkinson, _et al_. (92) presented half-life information for several of the pesticides using mutant pseudomonas bacteria.

Phenols

At concentrations of up to 500 mg/l almost complete reductions were demonstrated for most phenolic compounds, especially at contact times of 50 or more hours in acclimated systems. Several references reported greater than 70% reductions utilizing activated sludge processes (81,88,90,118). Leipzig and Hakenburg (58) showed 98.1% removals of nitrophenols using powdered activated carbon in an activated sludge system. Nathan (66) reported complete removals for several of the phenols employing mutant pseudomonas bacteria. Although toxic and inhibitory effects were noted for some compounds in the literature (109,124, 127), it appears that biological treatment can reduce even toxic compounds, e.g., 2,4,6-trichlorophenol, under suitable conditions (66,90,102,115).

Phthalates

Biological treatment was demonstrated to be effective in removing phthalate compounds. Removal efficiencies ranging from 50-100% were reported (21,81,90,100). Dryden, _et al_. (90), however, noted that a portion of these reductions may be attributable to absorption into cell tissue or air stripping.

Polynuclear Aromatics

All but two of the polynuclear aromatics were reported to be biorefractory or inhibited biological activity (108). Greater than 70% removal of napthalene at up to 500 mg/l and D-chloramphenicol were reported (56,81,100,101).

Chemical Coagulation

For purposes of this review, the category of chemical coagulation has been defined to include coagulation, flocculation, and precipitation. Additionally, filtration, sand or multimedia, often is included as an ancillary process. Typically, chemical coagulation has been used to remove inorganics, primarily heavy metals. Although most of the data examined pertained to metals removal, several documents report removal of organics with moderate success (6,21,90). Alum, aluminum sulfate, lime, and ferric chloride are the coagulants used most frequently.

Cohen (21) reports 15-56% removals of several aromatics, halocarbons, and phthalates at concentrations of 140-183 ppb using alum and dual media filtration. Dryden and Mayes (90) reported 60-90% reduction of phthalates at low ppb levels using aluminum sulfate. Becker and Wilson (6) reported 5-98% removal of several pesticides at low ppb levels using alum followed by sand filtration. Although reduction estimates were not provided, many polynuclear aromatics were reported to be removable by alum coagulation and gravity separation or sand filtration (90).

With regard to removal of metals by coagulation and filtration, reported reductions ranged from 0-100%. However, for each of the 22 metals for which quantitative reductions were reported, at least 30% removal was achieved with one of the coagulants enumerated earlier (16,34,63,64,90). Generally, arsenic, barium, beryllium, bismuth, cadmium, trivalent chromium, copper, iron, lead, manganese, mercury, nickel, silver, tin, titanium, vanadium, and zinc could be reduced by at least 90%.

Membrane Process - Reverse Osmosis

Reverse osmosis was shown to be less effective for separation of low molecular weight, polar organic compounds than for separation of inorganic salts. Two key criteria controlling separation are membrane characteristics and chemical nature of the molecule. Generally, separation of compounds with the same functional groups increased with increasing molecule size and branching. The following discussion illustrates the effectiveness of the various membranes.

Separation of alcohols ranged from 0-90%; cross-linked polyethylenimine (C-PEI) and aromatic polyamide (AP) membrane materials performed better than cellulose acetate (CA) (18,30).

Alcohols in order of decreasing percentage separation were i-propanol, ethanol, and methanol.

For aliphatics, separation varied considerably ranging from 0-90% (18,30). With the exception of dimethyl sulfoxide, aromatic polyamide and cross-linked polyethylenimine membranes performed better than cellulose acetate. Cellulose acetate membranes actually concentrated methyl acetate in the permeate. Trichloracetic acid demonstrated better separation than acetic acid by CA membranes but poorer separation by C-PEI membranes.

Similar results were reported for aniline. Using CA membranes aniline was concentrated in the permeate while C-PEI membranes achieved up to 80% removal (30).

Only limited data were available for aromatic compounds, however, C-PEI membranes again were superior providing 80-90% separation versus 3-7% for CA (18). Similar removals were observed for several ethers (18).

Separation of metal ions generally ranged from 85-100% at metal concentrations of 0.8 to 200 ppm and pH values of 8 to 11. Both CA and C-PEI membranes performed within this range (18).

Both CA and C-PEI membranes were capable of achieving 98-100% separations of numerous pesticides at concentrations of 42 to 1,579 ppb (18).

With CA membranes, concentration of phenol in the permeate was reported. However, 60-80% separation was reported for C-PEI membranes (18,30,90).

Membrane Process - Ultrafiltration

Very little information on the use of ultrafiltration for concentration of hazardous constituents in aqueous waste streams is available. The process has been applied efficiently in electropaint recovery, oil-emulsion waste treatment, and cheese whey separation. Molecules generally larger than 10^{-3} to 10^{-2} μ are retained in the concentrate stream (55).

In waste streams characterized by low suspended solids and high total dissolved solids, significant rejection of organic solutes was reported; e.g., 75% rejection of phenols at 100 mg/l (54) and 80-93% rejection of TOC in a 20 to 200 mg/l TNT containing wastewater (10). For the phenolic wastewater, rejection increased as pH increased with optimum rejection at pH 10, indicating that ionic state of the solute influenced rejection rate. Removal of metals in high suspended solids (125 to 1,550 mg/l) wastewater ranged from 79-89% at metal concentrations of 0.44 to 6.8 mg/l (59).

Stripping

Results of air and steam stripping experiments have been published for numerous organic compounds, particularly halocarbons. In other cases, certain compounds have been reported to be air or steam strippable even in the absence of experimental data because they possess relatively low boiling points.

As noted above, the majority of stripping data pertains to removal of halocarbons. A report by Coco, et al. (95) describes an extensive investigation on steam stripping of wastewaters from the petrochemical industry. Study conditions involved stripper feed flow rates of 250-325 ml/min, pollutant concentrations of 15 to 8,500 mg/l, overhead flows of 2-5% of feed flows, and various reflux flow to overhead flow ratios. Reductions of 75-99% between feed and bottoms were achieved at overhead flows of ≤5% of feed flow. In some cases refluxing with a reflux to overhead flow ratio of 0.9:1 enhanced concentration of the pollutant in the overhead with lower levels in the bottoms. Greater than 99% reductions of 1,1,2-trichloroethane, 1,1,2,2-tetrachloroethane, 1,1,1,2-tetrachloroethane, perchloroethylene, chloroform, 1,1-dichloroethylene, and 1,2-dichloroethylene were reported. Up to 75% TOC removals were reported concurrently. Residual TOC was in the form of chloral (trichloroacetaldehyde).

Numerous chlorinated and nonhalogenated aromatics have been studied or reported to be strippable. Results indicate reductions of 50-99.9% (13,64,90). Moreover, phenol and chlorophenols were reported to be steam strippable while napthalene and acrylonitrile were reported to be air strippable (90).

Solvent Extraction

Solvent extraction has been shown to be a viable alternative to stripping and adsorption processes when recovery of a valuable product is possible. Advantages claimed for extraction are that less energy is required than for stripping and that, as opposed to adsorption processes, feed stream concentration has little effect on equipment size. Generally, the C_4 and C_5 hydrocarbons are the best volatile solvents with iso forms preferred because of lower water solubility. For phenolic compounds, dual-solvent extraction (polar solvent and volatile solvent in series or in mixed extractor) is most appropriate. To select an appropriate solvent for the solute in the wastewater, equilibrium distribution coefficients (K_D), for solute/solvent pairs should be compared. The following criteria have been suggested by Earhart, et al. (27):

- If K_D values for important pollutants are >10, simple extraction with volatile hydrocarbon solvent is preferred.

- If K_D is <2, volatile solvent extraction is not recommended.

- Dual-solvent extraction is favored when K_D for both dual-solvent steps is ≥ 20 while K_D for direct volatile solvent is ≤ 5.

- If best polar solvent gives a K_D not more than twice the K_D for a volatile solvent, dual-solvent extraction probably is not warranted.

Although removals achieved by extraction are dependent on the solute-solvent pair being tested, results indicate that for many organic pollutants, especially aromatics, halocarbons, and phenols 90-99% removals can be achieved (27,95). Many organics in the other pollutant classifications also are reported to be extractable although quantitative results are not available (90). In addition, 99% reduction of mercury by extraction with high molecular weight amines and quartenary salts was reported (90).

Sorption Process - Carbon Adsorption

Activated carbon adsorption has been the most extensively applied concentration technology. Yet, much of the published data reflects pure compound or synthetic wastewater laboratory testing. Full scale process applications, especially for industrial wastewaters, are numerous; however, for a variety of reasons treatment data are not available.

Generally, carbon adsorption is most effective for materials of high molecular weight and low water solubility, polarity, and degree of ionization. It is difficult, however, to accurately predict performance of a carbon sorption system based solely on properties of the solutes which are present. For example, multicomponent system studies have shown that preferential or competitive adsorption can reduce removals of some compounds to 50-60% of values predicted from pure compound studies (35,40).

Various approaches to regeneration of spent carbon are being investigated. Although thermal regeneration is practiced most frequently, regeneration by solvent desorption has been reported to have varying success dependent upon solvent used and solute being desorbed (20). This provides the potential extraction and recovery of the solute from the solvent.

The following sections describe treatability of compounds in each of the 13 chemical classifications (except for the miscellaneous pollutants class) by carbon sorption.

Alcohols

Sorption of alcohols varies substantially ranging from about 3% to complete removal. Initial alcohol concentration greatly influenced removal; for example, at 100 μg/l propanol was completely removed (20) while at 1000 ppm about 19% reduction was reported (35). Adsorbability was found to increase with molecular weight (35). For compounds of less than four carbons the order of decreasing adsorption was undissociated organic acids, aldehydes, esters, ketones, alcohols (when more than four carbons, alcohols moved ahead of esters), and glycols (35). Aromatics had greater adsorption than aliphatics (35). Desorption of alcohols from carbon by elutriating with various solvents ranged from 4-110% (20).

Aliphatics

Sorption of aliphatics varied widely ranging from complete removal to less than 10% removal. Giusti, et al. (35) reported that results of two component isotherm tests could be predicted from single compound tests; however, in four component tests, only about 60% of predicted adsorption occurred. Continuous flow column studies produced 60-80% of theoretical isotherm capacity. Chriswell, et al. (20) reported that carbon was found to be more efficient for sorption of alkanes and chlorinated alkanes and alkenes, while resin sorption was more efficient for esters, alcohols, phthalate esters, phenols, chlorinated aromatic compounds, aromatics, amines, and pesticides. Neither were efficient for carboxylic acids. Using several solvents, Chriswell, et al. (20) reported generally less than 10% desorption of compounds from carbon with the exception of esters (insoluble in water and soluble in alcohols and ethers) where 35-71% desorption was observed.

Amines

Complete removal of all amines at 100 μg/l concentrations was reported (20). At 1000 ppm concentrations, removal ranged from 7.2-80.2% (35). Chriswell, et al. (20) reported that carbon was found to be more efficient for alkanes and chlorinated alkanes, while a resin was more efficient for esters, alcohols, phthalate esters, phenols, chlorinated aromatic compounds, aromatics, amines, and pesticides. Using several solvents, Chriswell, et al. (20) reported widely varying efficiencies in desorbing amine compounds from carbon. Desorption ranged from 0-82%, although, for 9 of 12 amines desorption was less than 38%.

Aromatics

Aromatics were reported to be sorbed better than undissociated organic acids, aldehydes, esters, ketones, alcohols, or glycols (35). Resins, however, were reported to sorb several aromatics more efficiently than did activated carbon (20). At concentrations of 0.1 to 6000 ppm, greater than 50% sorption was achieved for all aromatics reported with greater than 90% removal for many compounds. Desorption from carbon with solvent elutriation was poor, never exceeding 15% (20). Preferential adsorption was reported in several studies (35,40) with only 50-60% of the adsorption predicted from single compound studies occurring in multi-compound tests.

Ethers

At concentrations of approximately 1000 ppm adsorption varied from 13.5-100% generally increasing with increased molecular weight and branching (35). Carbon adsorptive capacity ranged from 0.039 to 0.200 g compound/g carbon at a sorbent dose of 5 g/l.

Halocarbons

Halocarbons in the concentration range 0.001-1000 mg/l were reported to be readily adsorbed by carbon. Removals of 75-100% frequently were reported. In several instances, halocarbon spills were treated successfully by an EPA mobile treatment trailer using carbon sorption technology (6). As with other chemical classes, sorption of halocarbons increased with molecular size (35). For many compounds, carbon sorption capacity was less in multi-component mixtures than in single compound solutions (21). Elutriation with solvents yielded 9-59% desorption of solutes from the carbon (20).

Metals

Carbon adsorption is not typically used for treatment of inorganics. McCarty, *et al*. (64) reported little or no reduction in arsenic, barium, cadmium, lead, manganese, and mercury and 35-80% removal of chromium, copper, iron, and zinc when initial metal concentrations were near analytical detection limits. At 100 mg/l concentrations, carbon doses of up to 10,000 mg/l yielded the following removals (72):

hexavalent chrome	36%
copper	96%
lead	93%
manganese	50%
mercury	99%
nickel	52%

PCBs

Activated carbon exhibits a strong affinity for PCBs. Contos, *et al*. (22) reported that concentrations of 1-160 ppb of Arochlor 1242 and 1254 were reduced to <1.0 ppb with carbon dosages of 4-100 mg/l. An EPA mobile activated carbon treatment trailer reduced PCB levels by 92.5-99.9% in wastewaters initially containing 1-400 ppb PCB levels (6).

Pesticides

Organic pesticides were removed effectively by carbon sorption. A publication by Becker and Wilson (6) cited several references of pesticide treatment with carbon. Reductions of greater than 80% were indicated with reductions frequently exceeding 99% at concentrations up to 4000 ppb. When TOC was used as an indicator of pesticide removal, TOC reductions of greater than 99% were reported at TOC values up to 10,000 mg/l (38). Sorption capacities for several pesticides were reported by Hager (38) and Bernardin, et al. (8).

Phenols

Carbon sorption is efficient for reduction of phenolic compounds. Removals of 92-100% at concentrations of 0.13-10 mg/l were attained by EPA's mobile treatment trailer (6). Chriswell, et al. (20) achieved virtually complete removal of various phenolic compounds at a concentration of 0.1 mg/l. Desorption from the carbon by elutriation with solvents proved ineffective. Illustrating several methods of pretreatment prior to carbon sorption, five full scale adsorption systems treating phenolic wastewater reported 83-99% TOC removals at TOC concentrations of 80-1,200 mg/l (38). Isotherm data including sorption capacities for several phenolic compounds were provided by Cohen (21).

Phthalates

Data on treatment of phthalate compounds is limited. Greater than 98% removal of bis(2-ethylhexyl) phthalate at 1,300 ppb was stated (5). Chriswell, et al. (20) reported complete removals of dibutylphthalate and dimethylphthalate at 100 ppb concentrations. Desorption by elutriation with solvents was poor. Activated carbon pretreatment improved phthalate removal by subsequent aluminum sulfate flocculation (90).

Polynuclear Aromatics

Adsorption of polynuclear aromatics is generally high. Chriswell, et al. (20) reported 80-100% reductions at 100 ppb concentrations. Poor desorption by elutriation with several solvents was indicated. Carbon used to further treat biologically and chemically treated wastewater achieved a 70% reduction of napthalene (64). Fochtman and Dobbs (31) provided isotherm kinetics for several polynuclear aromatics.

Sorption Process - Resin Adsorption

Generally, the principles which apply to carbon adsorption also apply to resin sorption. Major differences exist in initial cost of the sorbents and methods of regeneration. Carbonaceous and polymeric resins are severalfold more expensive than carbon. However, for some compounds, e.g., trihalomethanes, greater adsorption capacity by the resins has been demonstrated (46), thus smaller quantities of sorbents are needed. Also, it is claimed that the carbonaceous synthetic resins offer greater attrition resistance and regeneration flexibility (135). Solvent desorption rather than thermal regeneration (often used for carbon regeneration) provides the potential for recovery and reuse of sorbed solutes. This could offset the higher initial cost of the sorbents.

Resin sorption technology for the application of interest is not as well developed as carbon sorption technology. Therefore, less information exists on the former technology. Treatability of compounds in 10 of the 13 chemical classifications is described below.

Alcohols

Polymeric resin Amberlite XAD-2 provided complete removal of several alcohols at 100 μg/l concentrations (20). Desorption by elutriation with solvent varied from complete desorption to no desorption (20).

Aliphatics

Using a polymeric resin (Amberlite XAD-2) Chriswell, et al. (20) reported the adsorption of several chemical groups in order of decreasing sorbability, to be phthalate esters, aldehydes and ketones, alcohols, chlorinated aromatics, aromatics, esters, amines, chlorinated alkanes and alkenes, and pesticides. Sorption of aliphatics ranged from 25-100%. All but the chlorinated alkanes, chlorinated alkenes, and alkanes were removed better by the resin than by activated carbon. Acidic compounds were not sorbed well by either resin or carbon.

Desorption of aliphatics from resin by solvents ranged from little or no desorption to 50-72% for the esters (20).

Amines

As noted earlier, the adsorption of several chemical groups, in order of decreasing sorbability, was reported to be phthalate esters, aldehydes, and ketones, alcohols, chlorinated aromatics, aromatics, esters, amines, chlorinated alkanes and alkenes, and pesticides (20). Complete sorption of amines at 100 μg/l concentrations was reported. Amines were removed better by the resin than by activated carbon.

Desorption of amines from resin by solvents ranged from little or no desorption to 100%. Six compounds demonstrated less than 50% desorption while six others showed greater than 50%.

Aromatics

Using a polymeric resin, Amberlite XAD-2, Chriswell, et al. (20) reported complete sorption of nine aromatics with no desorption to 80% desorption from resin by elutriation with solvent. The order of decreasing sorbability was reported to be phthalate esters, aldehydes and ketones, alcohols, chlorinated aromatics, aromatics, esters, amines, chlorinated alkanes and alkenes, and pesticides. Resins sorbed aromatics more efficiently than did activated carbon. Because of the ability to regenerate with solvents, resins were reported to be less costly for treatment of wastewaters containing TNT (2). However, for munitions wastewaters carbon was reported to have a greater absorption capacity (lb. nitrobodies adsorbed per lb. sorbent) than did Amberlite XAD-4 (40).

Halocarbons

Some of the resin adsorbents demonstrated a strong affinity for halocarbons. Using Amberlite XAD-2, Chriswell, et al. (20) showed complete removals of several halocarbons. Desorption of these compounds from XAD-2 by elutriation with a solvent ranged from 28-100% (20). Physical properties, equilibrium capacities, and results of a column study comparing carbonaceous resins to activated carbon were described by Tsacoff and Bittner (46). Their study indicates that per cubic foot, the resin treated approximately twice as much groundwater as did carbon before comparable breakthrough occurred.

PCBs

Arochlor 1254 at a concentration of 100 ppb was completely sorbed by Amberlite XAD-2 (20). Chriswell, et al. (20) also stated that 76.6% could be desorbed using the proper solvent. Lawrence and Tosine (57) studied the adsorption of PCBs from synthetic aqueous solution and raw sewage. They reported 60% reduction of Arochlor 1254 using Amberlite XAD-4 and about 23% reduction of Arochlor 1260 using Amberlite XAD-2 at PCB concentrations of 1-25 ppb.

Pesticides

Several case studies of resin adsorption of pesticides cited by Fox (32) reported at least 94% removal at pesticide concentrations ranging from 0.07 to 1,500 mg/l. Kennedy (49) showed Amberlite XAD-4 was more effective than activated carbon in treating a wastewater effluent from a pesticide manufacturer. At chlorinated pesticide concentrations ranging from 33-118 mg/l XAD-4 processed about four times more wastewater than carbon before comparable leakages occurred. Leakage could be maintained at <1 mg/l for at least 120 BV. While resin was readily regenerated with isopropanol, carbon was very poorly regenerated. It was noted that acetone was a more effective regenerant, but that it is highly flammable. Amberlite XAD-2 achieved complete removals of several pesticides at 100 ppb concentrations with 10-49% desorption by solvent elutriation (20).

Phenols

Chriswell, et al. (20) reported complete reductions of several chlorinated phenolic compounds at 100 ppb levels using Amberlite XAD-2. Washing of the resin with various solvents yielded 35-76% desorption of the solutes. Crook, et al. (23) cited several case studies of industrial wastewater treatment by resin sorption. For initial phenolic compound concentrations of 280-6,700 ppm, sorption capacities of 16-87 g of solute/l of resin were reported for Amberlite XAD-4 and XAD-7. Less than 1 mg/l phenol leakages were attained. Elutriation with methanol, ethanol, and acetone provided effective regeneration. The application of macroreticular ion exchange resins and polymeric adsorbents to waters containing 10-1,800 mg/l concentrations of phenols, dichlorophenol, and nitrophenol yielded greater than 99% removal (33).

Phthalates

Dibutyl phthalate, diethylhexyl phthalate and dimethyl phthalate were completely adsorbed at 100 ppb concentrations by Amberlite XAD-2 (20). Desorption of the solutes from XAD-2 by solvent elutriation ranged from 62-100%.

Polynuclear Aromatics

Amberlite XAD-2 resin completely removed several polynuclear aromatic compounds at initial concentrations of 100 ppb (20). Solute desorption from the resin by solvent elutriation ranged from 41-63%.

Sorption Process - Miscellaneous Adsorbents

In addition to carbon and the synthetic resins, other natural and synthetic sorbents have been studied. Limited data for two chemical classifications, metals and PCB's, have been reported. These are summarized below.

Metals

Dryden, et al. (90) reported on a variety of materials including silicon alloy, high clay soil, ground redwood bark, silicon oxide and calcium oxide slags, for sorption of metals. Copper and chromium at concentrations of 300 mg/l were completely sorbed on a high clay soil. Silicon alloy adsorption reduced 10-25 mg/l arsenic, cadmium, copper, lead, mercury, and zinc concentrations by >96%.

PCBs

Lawrence and Tosine (57) studied adsorption of PCBs from synthetic aqueous solutions and raw sewage. At concentrations of 1-25 ppb, Arochlor 1254 and 1260 were reduced 73% using PVC chips and 35% using polyurethane foams.

SECTION 8

PROCESS TRAINS

Since hazardous aqueous waste streams vary widely in composition and often contain a diversity of constituents, in general, no single unit process is capable of providing optimum treatment. Rather, arrangement of individual processes into process trains is necessary to achieve high levels of treatment in the most cost-effective manner. In this section the formulation of several process trains is discussed. Although not necessarily universally applicable, these process trains have been judged to be broadly applicable to many of the leachate, groundwater, and surface water quality problems identified.

Both selection of the unit processes based upon literature review results and formulation of process trains with broad applicability are described. Performance potential of each train was examined using three wastewaters of differing quality. This "desk-top" evaluation was conducted both independently and with input from representatives of companies marketing the technologies. Based upon these evaluations, priorities were established for subsequent laboratory bench scale evaluations using actual wastewater.

EVALUATION OF UNIT PROCESSES

Summary

Evaluation of candidate technologies led to the conclusion that the following unit processes have greatest broad range applicability to concentration of hazardous constituents of aqueous waste streams:

- biological treatment
- chemical coagulation
- carbon adsorption
- membrane processes
- resin adsorption
- stripping

These, however, must be supplemented with ancillary processes such as sedimentation and filtration.

Conclusions on all of the candidate technologies which led to the selection of the above unit processes are summarized below.

1. Biological Treatment - This process was found to be applicable to the treatment of a wide variety of waste streams. Concentration as well as degradation and stripping may occur during biological treatment. For several of the chemical classifications presented earlier, the following performances were observed:

a. alcohols - generally removals of 75%-100% reported.

b. aliphatics - wide range of efficiencies reported.

c. amines - some amines were readily degradable with acclimated cultures while others were shown to inhibit oxygen consumption.

d. aromatics - generally high removal reported; however, many compounds are biorefractory and removal may be due to air stripping or adsorption to biomass.

e. halocarbons - generally reported to be biorefractory; removals attributed to biological treatment may be due to air stripping.

f. metals - at below toxicity thresholds metal removals were reported; however, at higher concentrations toxic and inhibitory effects were noted.

g. pesticides - no significant degradation reported.

h. phenols - greater than 70% removals frequently were reported; toxicity effects also were noted.

i. phthalates - high removals reported may be attributed to absorption into cell tissue or air stripping.

j. polynuclear aromatics - generally reported to be inhibitory or biorefractory.

2. Carbon Adsorption - Of the processes evaluated, the greatest amount of information on hazardous waste applications existed for carbon adsorption. Continuous flow systems using granular carbon in contact columns and powdered carbon in biological treatment systems as well as batch treatment for spill incidents have been reported. Generally, it was found that adsorbability increased with increasing molecular weight. For compounds of less than four carbons, the order of decreasing adsorption was undissociated organic acids, aldehydes, esters, ketones, alcohols (when greater than four carbons, alcohols moved ahead of esters), and gylcols. Aromatics had greater adsorption than aliphatics. Adsorption capacity for a specific compound is affected by other compounds present in the waste stream. Because of this

competitive adsorption, caution must be exercised in basing system design on case history results.

3. Catalysis - Deemed to be a destruction or detoxification rather than a concentration process; found to be highly compound-specific and poor for mixed streams.

4. Centrifugation - An ancillary process for concentration of high suspended solid waste streams.

5. Chemical Coagulation - Numerous reports exist on the removal of heavy metals by chemical coagulation with lime, alum, iron and sulfides. At ppb levels, moderate removals (30%-65%) were reported for several aromatics, halocarbons, pesticides, phthalates, and polynuclear aromatics using alum.

6. Crystallization - Process considered to be inapplicable. It is reported to be complex to operate and cannot readily handle variations in wastewater composition. There are no commerical operations and there has been very little research since the mid-1970's.

7. Density Separation - an ancillary process applicable primarily to particulate or insoluble species; may be used with other chemical processes.

8. Dialysis/Electrodialysis - Dialysis is most effective on feed streams with high concentrations of low molecular weight dissolved species. It is a low flux rate process with both output streams more dilute than the feed stream. Electrodialysis does not affect undissociated species, is complex to operate, can be fouled by high concentrations of organic compounds, and is applicable on streams with TDS levels of less than 5000 mg/l. Neither of these processes were deemed to have a high potential for the application of interest.

9. Dissolved Air Flotation - An ancillary separation process which can be used in conjunction with chemical coagulation. The process frequently has been used for concentration of biological sludges and separation of oils in water.

10. Distillation - Distillation is not expected to have broad application to mixed waste streams. Only when credits for recovered materials are considered does the process compete economically with other concentration techniques.

11. Evaporation - Not expected to have broad application because the moderately volatile organics (boiling point of 100°-300°C) will appear in evaporator condensate. Good clean separations may not be possible without post-treatment. Energy usage is high and both capital, and operating and maintenance costs are high.

12. Filtration - Ancillary process to remove particulates.

13. Ion Exchange - Primarily for treatment of inorganic ions; however, heavy metals usually can be removed less expensively by other chemical-physical processes. Not considered to have a high potential.

14. Resin Adsorption - Comparable in principle to carbon adsorption; however, resins usually are solvent regenerated. Using polymeric and carbonaceous resins, it is possible to adsorb a broader range of compounds than generally reported for carbon. It has been reported that resins were more efficient than carbon for removal of esters, alcohols, phthalate esters, phenols, chlorinated aromatics, aromatics, amines, and pesticides. However, results depend on the resins used. Experience with resin adsorption is much more limited than experience with activated carbon.

15. Reverse Osmosis - Reverse osmosis (RO) is applicable to treatment of waste streams low in dissolved and suspended solids. It may be necessary to employ suspended solids removal processes prior to RO to remove particles of >25 μ. Performance is heavily dependent on membrane material and configuration. While typically applied to inorganics, up to 90% removal of a variety of organics has been reported. However, some membranes tend to concentrate some organics, e.g., aniline and phenol, in the permeate rather than concentrate stream. For the application of interest, RO probably would have to be paired with biological treatment or stripping for further treatment of the permeate stream. The concentrate stream also would need additional handling.

16. Solvent Extraction - Potentially applicable when a single or a few reuseable compounds are present. Generally not suitable for waste streams containing a variety of organics at low part per million or part per billion concentrations.

17. Stripping - Air and steam stripping have been used to remove numerous volatile, low molecular weight organics. Because stripping probably will remove predominantly biodegradable rather than refractory organic compounds, bottoms will require additional treatment possibly using an adsorption process. Although only limited data could be obtained, removal of aromatics, halocarbons, phenols, and polynuclear aromatics were reported to range from about 50% to 90%. Considered to be potentially applicable.

18. Ultrafiltration - Whereas reverse osmosis can remove dissolved ionic species, UF basically is a filtration process capable of removing insoluble materials and organics of >1000 molecular weight. To date, applications have been largely in the area of waste paint recovery, protein recovery from cheese whey, and treating oil emulsions. Further processing of the permeate would be necessary. Judged to be of limited potential.

Discussion of Selected Processes

Biological Treatment

Biological treatment is expected to offer the most cost-effective approach to removal of organic matter particularly biodegradable substances which are not amenable to sorption processes. The major problem confronting the use of biological treatment is the potential presence of toxic organics and heavy metals which may interfere with metabolic processes and render this treatment approach ineffective. There are several categories of biological treatment processes including variations within these categories which overcome toxicity problems to some extent. In addition, pretreatment or the addition of powdered activated carbon often can be applied successfully to overcome toxicity problems. For example, toxic heavy metal concentrations may be reduced below limiting concentrations by chemical coagulation, such as lime, alum, or iron precipitation, prior to biological treatment. Carbon sorption either by packed bed pretreatment or PAC addition to the biological treatment unit can be quite effective in dealing with toxic substances. Nutrient addition (e.g., phosphorous) will probably be required in many instances.

Biological treatment processes which can be used include activated sludge, trickling filters, aerated lagoons, and anaerobic filters. Each is discussed below.

Of the various activated sludge processes, completely mixed, extended aeration, and contact stabilization are used most often. The complete mixed configurations are more tolerant of toxic substances than plug flow schemes. The impact of toxic substances in the wastewater is reduced because complete mixing in the aeration unit reduces constituent concentration by dilution and distributes the load to a greater quantity of biomass. Non-biodegradable substances may pose more of a problem than biodegradable toxics especially if sorbed by the biological sludge where they may concentrate over a period of time and interfere with cell metabolism.

Sludge produced may be a hazardous waste due to the sorption and concentration of toxic substances contained in the wastewater. The quantity of sludge produced is normally governed by hydraulic detention time and sludge age. The conventional approach focuses on maximum sludge production consistent with the desired effluent quality. On the other hand, extended aeration aims to minimize sludge production at the expense of long detention times. Extended aeration typically is used in small operations since the small sludge handling requirements minimize the amount of manpower needed for operation (manpower costs are more significant than aeration costs for small units).

It is doubtful that activated sludge treatment alone will suffice to meet discharge objectives in most instances. Pretreatment is expected to be needed not only to meet discharge requirements but also to remove toxic materials which would interfere with optimum performance of the biological system. Post-treatment normally serves to polish the effluent by removing refractory substances. These generally are expected to be in much lower concentrations than biodegradable substances. Listed below are potentially useful pretreatment steps:

1. Chemical coagulation which can consist of lime, alum, or iron salt addition to form precipitates which scavenge toxic substances such as heavy metals from the wastewater.

2. Carbon sorption which may either be accomplished through PAC addition with or without chemical coagulation or by packed beds of granular carbon. The objective is reduction of toxicants to facilitate biological treatment; therefore, large throughputs for packed beds or small PAC additions may be all that is required to achieve this reduction if the toxicants are strongly sorbed by the carbon.

3. Ultrafiltration or reverse osmosis are potential pretreatment candidates. These would be aimed at removing large molecular species which typically include the toxic and refractory species while smaller species which are generally biodegradable (e.g. ethanol, acetone) carry through and are removed in the biological unit.

4. Steam stripping may be useful in some instances but is more likely to remove a large fraction of biodegradable TOC than the refractory TOC.

5. Aeration, sedimentation and filtration may also be useful in some instances. For example, ferrous iron may be oxidized and precipitated to scavenge other heavy metals. Sedimentation with or without filtration could then remove the precipitated ferric hydroxide and reduce toxic heavy metals to acceptable levels.

6. Chemical oxidation, with ozone for example, may serve to detoxify certain materials; however, ozone consumption may be high due to oxidation of materials, such as ethanol, which are more appropriately biodegraded at much less cost.

7. Wet air oxidation also may detoxify some organic substances but is expected to be a costly pretreatment step.

8. Ion exchange can remove toxic metal ions but is probably more expensive than chemical coagulation.

9. Electrochemical treatment may be useful in some instances, e.g. it may be preferable to chlorination for reduction of high cyanide concentrations.

Candidate post-treatment steps include:

1. Carbon sorption has strong potential when teamed with biological. Biological treatment can substantially reduce the load to a carbon column and thereby minimize the cost.

2. Resin sorption is an alternative to carbon sorption and may be less costly if steam and/or solvent regeneration are effective.

3. Chemical coagulation - sedimentation - filtration would be useful for removing residual heavy metals. Some PAC addition may also be performed to clean up low residuals of toxic organics.

Other steps, such as ion exchange, membrane processes, steam stripping, oxidation, are not considered to be good post-treatment candidate processes.

Trickling filters will not produce as high a quality effluent as activated sludge, but may be less troublesome from an operation standpoint. Pre- and post-treatment comments on activated sludge also apply to trickling filters.

Although generally effective, because of their large surface area, containing and collecting off-gases from aerated lagoons would pose a problem. Removal of hazardous sludge from the lagoon also may be a problem.

Anaerobic treatment may have advantages over aerobic treatment because of less off-gas and sludge production. These processes are less susceptible to upsets by many toxic substances such as heavy metals. Possibly, methane produced in the process could be used as fuel. Disadvantages include low quality and effluent necessitating further treatment and generally greater operational difficulty. Successful application of anaerobic treatment of leachate from municipal landfills has been reported on a bench scale level. Pre- and post-treatment considerations discussed for activated sludge also apply.

Chemical Coagulation

The term chemical coagulation as used here includes the processes of chemical addition, precipitation, flocculation, and sedimentation. Typically, it is a process used for the removal of particulate matter and inorganic ions, primarily heavy metals. Generally, precipitation is accomplished by adding alum, lime, iron salts (ferric chloride, ferrous sulfate), or hydrogen or sodium sulfide. Organic polyelectrolytes also are used as flocculants or to aid flocculation. A primary variable in determining coagulation chemical doses and removal efficiences is pH because of its effect on pollutant solubility in the wastewater solution. Although removals equal to solubility limits are theoretically possible, the formation of organometallic complexes and the incomplete removal of precipitated particles limits actual removal efficiencies.

When organics are present, post-treatment for organics removal will be required. This could take several forms including biological, sorption, or stripping. Reports indicate, however, that coagulation followed by efficient solids removal, e.g. dual media filtration can provide moderate removals (30-60%) of numerous organic compounds; even when these compounds are present at the low mg/l or ppb levels. Provisions also are required to manage sludges generated by the coagulation process.

Sorption Processes

Activated carbon sorption with packed beds is considered to be a prime candidate for leachate treatment. However, it is anticipated that activated carbon will be used in conjunction with other processes since it is quite expensive to treat moderate to high TOC loads with carbon alone. Furthermore, carbon is not effective for removing many highly soluble low-molecular weight organics. Although most of the low-molecular weight organics are not highly toxic, they will contribute substantially to the COD and BOD of the effluent. Carbon sorption is best suited for removal of refractory organics following biological treatment. These organics generally are adsorbed most strongly by the carbon and at the low concentrations typically found, the carbon sorption cycle can be lengthened. Consequently, the cost of carbon replacement or regeneration is lowered.

If the sorption unit is small, it is unlikely that on-site thermal regeneration of activated carbon will be performed. Instead, commercial replacement services probably would be used. Adsorption by synthetic polymeric and carbonaceous resins is an alternative to activated carbon sorption in some situations. There are, however, several major differences between the two types of sorbents:

1. Acids, caustics, hot water, steam, and solvents (acetone, methanol, chloroform, methylene chloride, and mixtures) are used to regenerate spent resins. This permits recovery of desorbed solutes provided that:
    - there is a solute reuse potential,
    - costs for recovery of solute (and credits for recovery) and regeneration of solvent do not

exceed costs for disposal and replacement of spent solvent.

It also is useful where thermal regeneration is not possible, e.g., when nitrobodies from munitions waste are adsorbed; or high inorganic dissolved solids would result in scale formation during thermal regeneration;

2. Resin sorption kinetics are more rapid;
3. Resins generally have lower adsorption capacities;
4. Resins are more resistant than carbon to attrition losses;
5. Selective adsorption is possible by applying the proper resins in the correct sequence; and
6. Costs for resins range from \$11-33/kg (\$5-15 per pound) as compared to \$1.1/kg (\$0.50 per pound) for carbon.

At this time, there are limited full scale applications of the resin process. Phenol, pesticide, munition wastes, and contaminated groundwater have been successfully treated using various resins.

Alternative pretreatment steps for the sorption process include the following:

1. Biological treatment (discussed earlier);
2. Solids removed by filtration;
3. Chemical coagulation for suspended solids and heavy metals removal followed by sedimentation alone or filtration alone, or a combination of sedimentation and filtration;
4. Aeration followed by sedimentation/filtration for oxidation and precipitation of dissolved iron which removes heavy metals as well as suspended solids. Aeration also may remove volatile organics to relieve loading on activated carbon;
5. Ozonation to render organics more sorbable by carbon; and
6. Steam stripping may be effectively used for removing relatively high concentrations of volatile sorbable organics to reduce loading on carbon. It may be possible also to reduce concentrations of nonsorbable volatile

species such as lower alcohols, aldehydes, ketones, and perhaps acetic acid. The cost may be high however.

Processes such as ultrafiltration and reverse osmosis do not complement sorption and are not considered good pretreatment candidates. Ion exchange possibly may serve to remove ionic substances such as heavy metals, organic acids, amines, or cyanide; but it is likely that alternative processes will be less expensive.

Post-treatment processes which may be useful include the following:

1. Precipitation - scavenging for removal of residual heavy metals.

3. Biological - for removing biodegradable residuals.

Membrane Processes

Reverse osmosis and ultrafiltration are considered to be possible candidates for treatment of leachate and other contaminated waters. Reverse osmosis should be used only for waste streams relatively low in dissolved solids because treatment of highly mineralized water would result in a high volume concentrate stream. Ultrafiltration may be used on wastes high in dissolved solids because high molecular weight species are separated while dissolved salts pass into the permeate stream. This would be permissible in instances where the presence of dissolved salts in the process effluent is deemed acceptable.

It is anticipated that a suspended solids removal pretreatment step will be required in most instances to produce a clear feedwater to the membrane process. The membrane should remove the toxic and refractory species leaving biodegradable organics for post-treatment by a biological process. It is possible that steam stripping could serve to remove low molecular species prior to the membrane process to eliminate the need for biological processing.

Treatment of the brine or concentrate streams from the membrane unit must also be considered. Evaporation and incineration are potential treatment processes for these concentrates. Solidification also is an alternative.

Stripping Processes

Two types of stripping processes, air and steam stripping, are possible. Although both can be conducted in packed towers, steam stripping actually is a fractional distillation process with significantly greater energy demands. Typically, air stripping has been used for removal of ammonia from domestic wastewater. Steam stripping has been used for ammonia and hydrogen sulfide removal from industrial wastes; soluble, low molecular weight volatile organics removal (e.g. methanol) from high BOD waste streams; and more recently, removal of water immiscible organics (e.g. chlorinated hydrocarbons) from process wastewaters. Because of potential for air pollution caused by removal of volatile organics, air stripping is deemed to have more limited utility. Steam stripping, however, may be more attractive, especially if:

1. recovery of the pollutant in the condensate stream from a binary pollutant/water mixture is possible (practiced frequently in process wastewater treatment), or

2. pollutant load on downstream treatment processes can be reduced.

The efficiency of steam stripping is influenced by feedwater temperature and pH. Pretreatment steps would include pre-heating of feed concurrently with condensate or bottoms cooling and pH adjustment. The extent of pH adjustment necessary will be dependent on the pH of the waste stream and the pollutants present. Chemical coagulation and sedimentation or filtration for metals and suspended solids removal also may be required.

If recovery of a pollutant(s) in the condensate stream is not possible, two streams (condensate and bottoms), both needing additional treatment, are generated. If this is the case, steam stripping could be of marginal utility since cost-effectiveness is dramatically affected if there is no credit for recovered materials. Frequently, incineration will be the best disposal approach for organics-rich condensates. Condensate volumes ranging from 2-5% of feed flow have been reported. By refluxing a portion of the total condensate stream or the water phase if an organics-water separation occurs, the condensate can be further concentrated.

Bottom streams generally will be better suited to treatment by adsorption processes because stripping will remove the less sorbable soluble, volatile, low molecular weight organics. Refractory and the more biologically toxic organics probably will remain. Therefore, biological treatment will have less applicability. Treatment of bottoms by membrane processes also may be feasible although less attractive than sorption.

FORMULATION OF PROCESS TRAINS

Having identified the most promising unit concentration technologies, the next step was to formulate process trains which combined technologies in a fashion which would provide broad spectrum treatment capability. The objective was to identify process trains which would produce high quality effluents when applied to the wide range of waste stream compositions likely to be encountered. Five such process trains incorporating the selected concentration technologies were formulated and are illustrated in Figures 1-5. Each of these process trains has particular strengths and weaknesses as discussed subsequently. One or more of these process trains should be applicable to almost any situation dictating concentration of a hazardous aqueous waste.

Process Train 1

Figure 1 illustrates a sequence of biological treatment followed by granular carbon sorption. This train is applicable to treatment of wastewaters high in TOC, low in toxic (to a biomass) organics, and containing refractory organics. Chemical coagulation and pH adjustment are provided for heavy metal removal and protection of the subsequent biological system. This may not be necessary if heavy metal concentrations are below toxicity thresholds and if the moderate removal efficiencies typical of activated sludge (20-60% although both poorer and better performances have been reported for some metals) are sufficient. When combined with additional metals removal by activated carbon or resin sorption sufficient removal may be achieved without chemical coagulation. Biological treatment such as activated sludge, rotating biological contactors, or anaerobic filters is included to reduce BOD as well as biodegradable toxic organics. This reduces the organics load to subsequent sorption processes. To prevent rapid head losses caused by accumulation of solids in the sorption columns, clarification and multi-media filtration are provided. The intent is to reduce suspended solids to 25-50 mg/l. Granular carbon adsorption is included to remove refractory organic residuals and toxic organics. Activated carbon rather than polymeric or carbonaceous resins has been specified because more full scale experience exists and performance as well as design and operating criteria have been reported. As previously noted, some concomitant removal of heavy metals also can be expected to occur. This process train is expected to be highly effective and the least costly. Its success, however, is dependent on biological system performance. Moreover, the presence of high concentration of volatile organic constituents may create a potential air contamination problem. Three by-product wastes are produced: chemical sludge, biological sludge, and spent carbon. Spent carbon can be regenerated but the sludge must be disposed.

Because the process is intended to handle multi-component waste streams, pollutant recovery for reuse is unlikely. The only potential for such recovery is during carbon regeneration if materials can be desorbed by steam or solvent washing. This would be reasonable only if a small number of separable compounds were sorbed on the carbon.

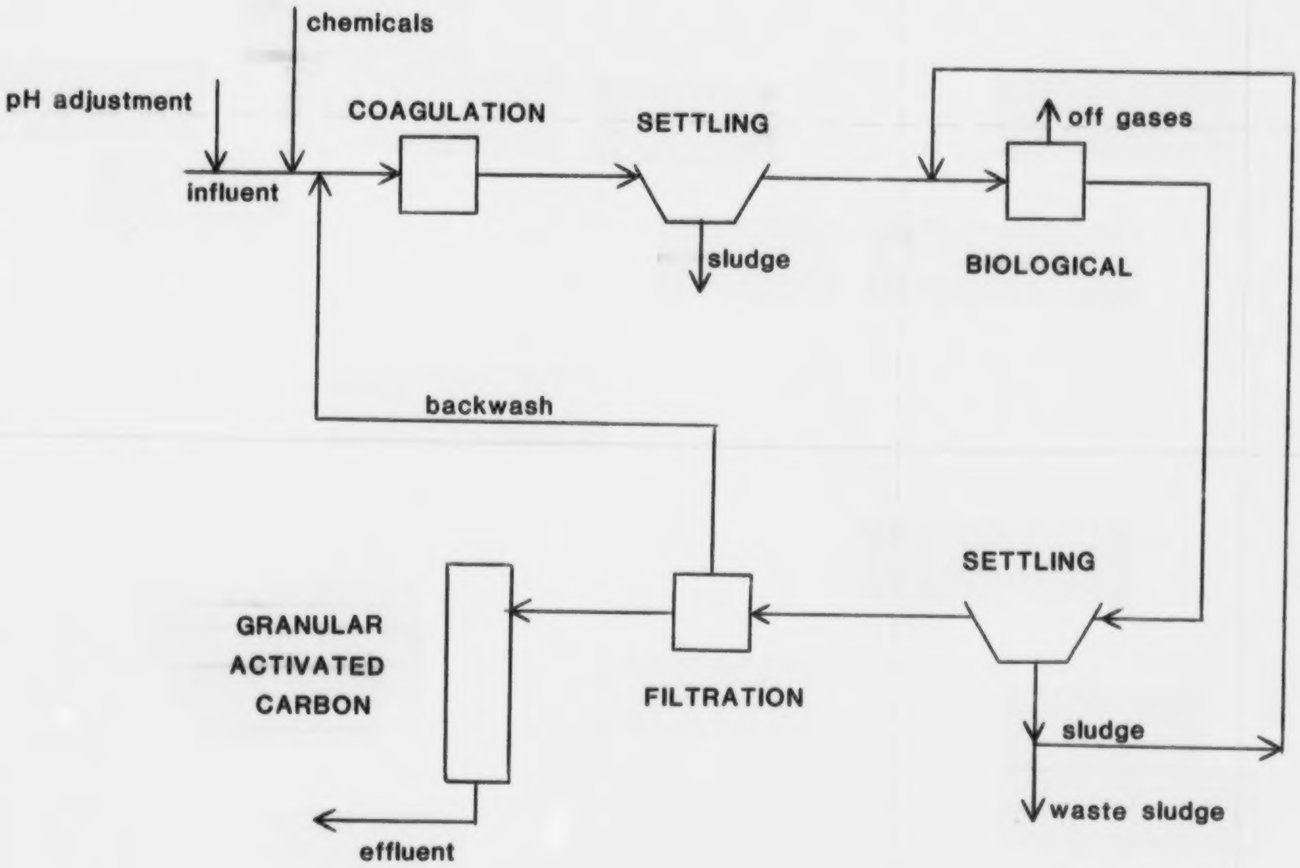

Figure 1. Schematic of biological/carbon sorption process train.

Process Train 2

The flowsheet depicted in Figure 2 employs the same unit processes as in Figure 1, but granular carbon is positioned ahead of biological treatment. This process train which also is applicable to high TOC wastewaters, was designed to respond to situations where waste stream components may be toxic to biological cultures. The rationale is to utilize the activated carbon to protect the biological system from toxicity problems. Therefore, the carbon would be allowed to "leak" relatively high concentrations of TOC (organics) rather than be operated to achieve maximum reduction of organic compounds. Allowable leakage would be based upon determination of the point which the carbon treated effluent becomes toxic to the subsequent biological process. Thus, the selection of the allowable TOC or organics leakage (i.e., breakthrough) from the carbon contactors is crucial to the performance and cost effectiveness of this process train. If biologically toxic organics are present, treatability studies must be conducted for several reasons, one of the primary being to establish the acceptable breakthrough level. Higher organic loads handled by the biological system result in greater service life of the granular carbon and consequently, lower costs related to the carbon treatment phase.

In this configuration, the chemical coagulation step (including settling and filtration) plays a role both in soluble inorganics removal and in particulate removal to minimize head losses in contact columns.

As with the process train in Figure 1, there is little potential for recovery of pollutants.

Process Train 3

The third process train, illustrated in Figure 3, utilizes biophysical treatment which is a combination of biological and powdered activated carbon treatments conducted simultaneously. This approach is simpler than the previously described sequential carbon-biological treatments and has the potential of achieving comparable effluent quality. Potential advantages include the use of less costly carbon (powdered vs. granular) and minimization of physical facilities required. Spent carbon-biological sludge can be regenerated or dewatered and disposed directly. However, if the latter approach is considered, it is necessary to include cost for disposal of toxics-laden carbon when making economic comparisons.

Complete mix activated sludge or contact stabilization are the two biological processes most frequently used. Recent reports suggest operating at long solids retention times (i.e. sludge ages of 100-150 days) and mixed liquor suspended solids concentrations of 20,000-25,000 mg/l with 60% being PAC and 40%

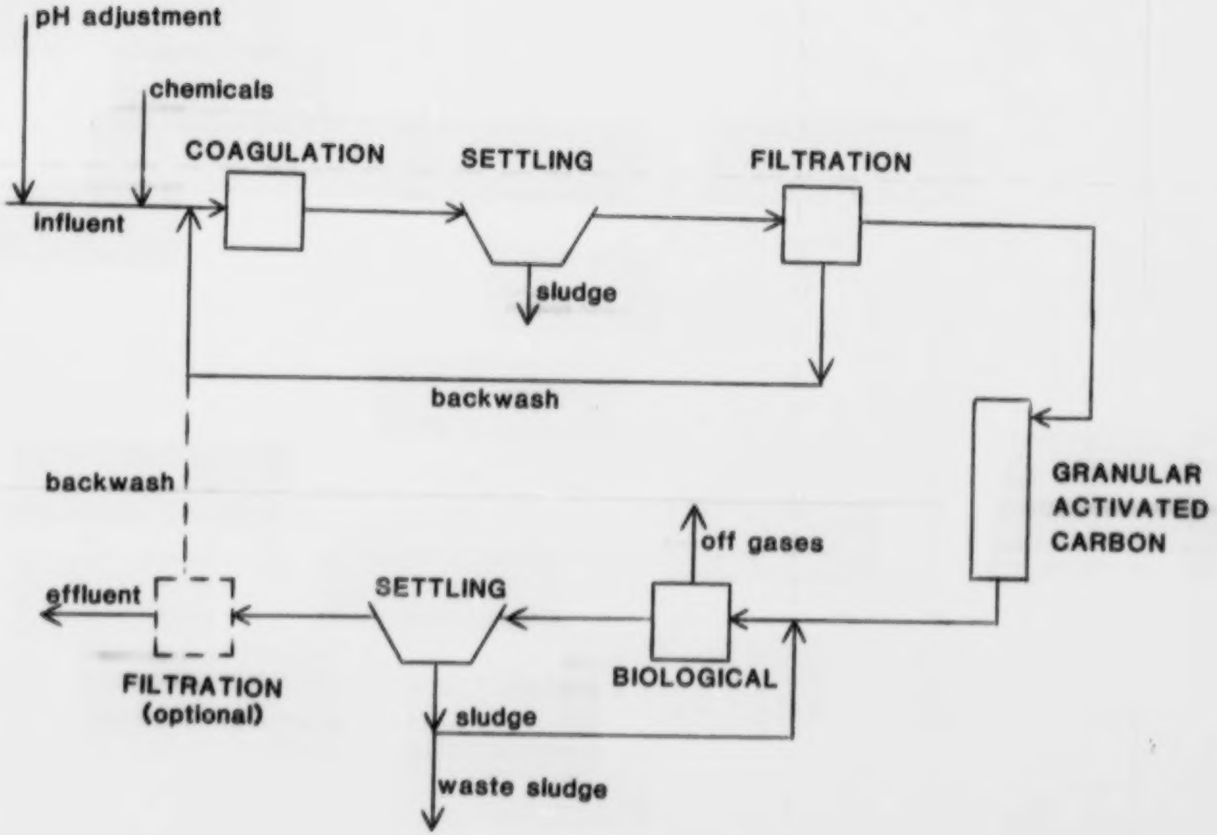

Figure 2. Schematic of carbon sorption/biological process train.

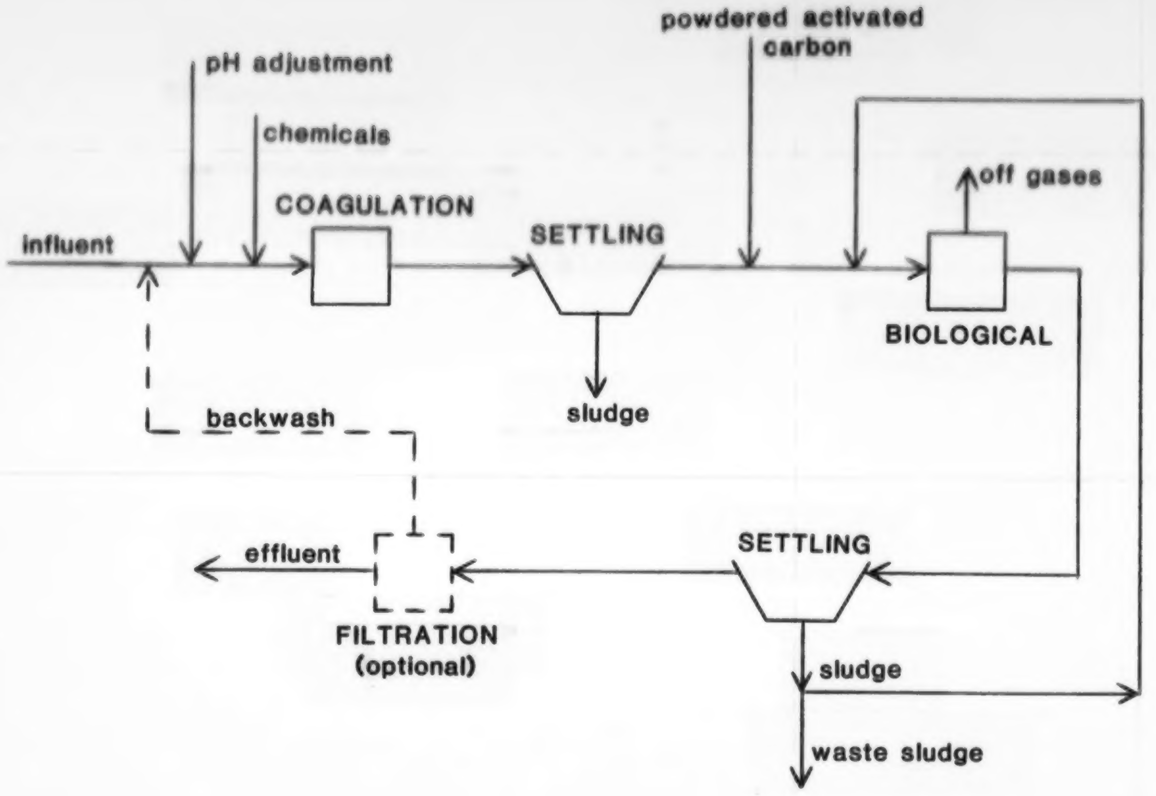

Figure 3. Schematic of biophysical process train.

being biomass.

Process Train 4

Figure 4 illustrates the use of a membrane process preceding biological treatment. This configuration would be applicable to wastewaters containing organic and inorganic pollutants. Selection of the appropriate membrane process, ultrafiltration and/or reverse osmosis, would depend upon wastewater composition and treatment goals. Ultrafiltration is a membrane process capable of separating high molecular weight (mw $> \sim 1000$) species from a liquid stream on the basis of size. Reverse osmosis utilizes a semipermeable membrane to concentrate numerous dissolved species both organic and inorganic. Salinity is an important factor to be considered since UF will allow dissolved salts to enter the permeate stream while RO will not. Therefore, use of RO on high salinity waste streams is questionable because large volumes of concentrate are generated. Numerous RO membrane materials and configurations are available. Aromatic polyamide and cross-linked polyethylenimine materials have performed better than cellulose acetate. Membrane module configurations include hollow fiber, spiral wound, tubular, and flat sheet. Different configurations provide different surface areas, flux rates, flow velocities, and other process variables. Care must be exercised in selecting membrane materials and configurations. Organic removals of 20-70% have been reported for RO, although some membranes, e.g. cellulose acetate, tend to concentrate some organics, e.g. phenol and aniline, in the permeate stream.

A biological process was paired with the membrane process to address low molecular weight organics. Alternatively, stripping processes could be paired with membranes. Sorption processes were not considered in conjunction with membranes because of the likelihood that the lower molecular weight, readily soluble organics would pass through the system.

A major disadvantage of the process train depicted in Figure 4 is that membrane processes generate concentrate streams which require additional handling and disposal. The concentrate stream flow may be 10-20% of the feed flow.

Process Train 5

A processing system consisting of stripping and carbon adsorption is illustrated in Figure 5. This configuration will be applicable primarily to organic wastewaters although chemical coagulation for inorganics and particulate removal is provided. This flowsheet is suited to situations involving volatile and refractory or toxic organics. It is especially pertinent if a single or limited number of volatile compounds which can be recovered from the overhead condensate stream (if steam stripping is used) are present. Even though the wastewater may contain

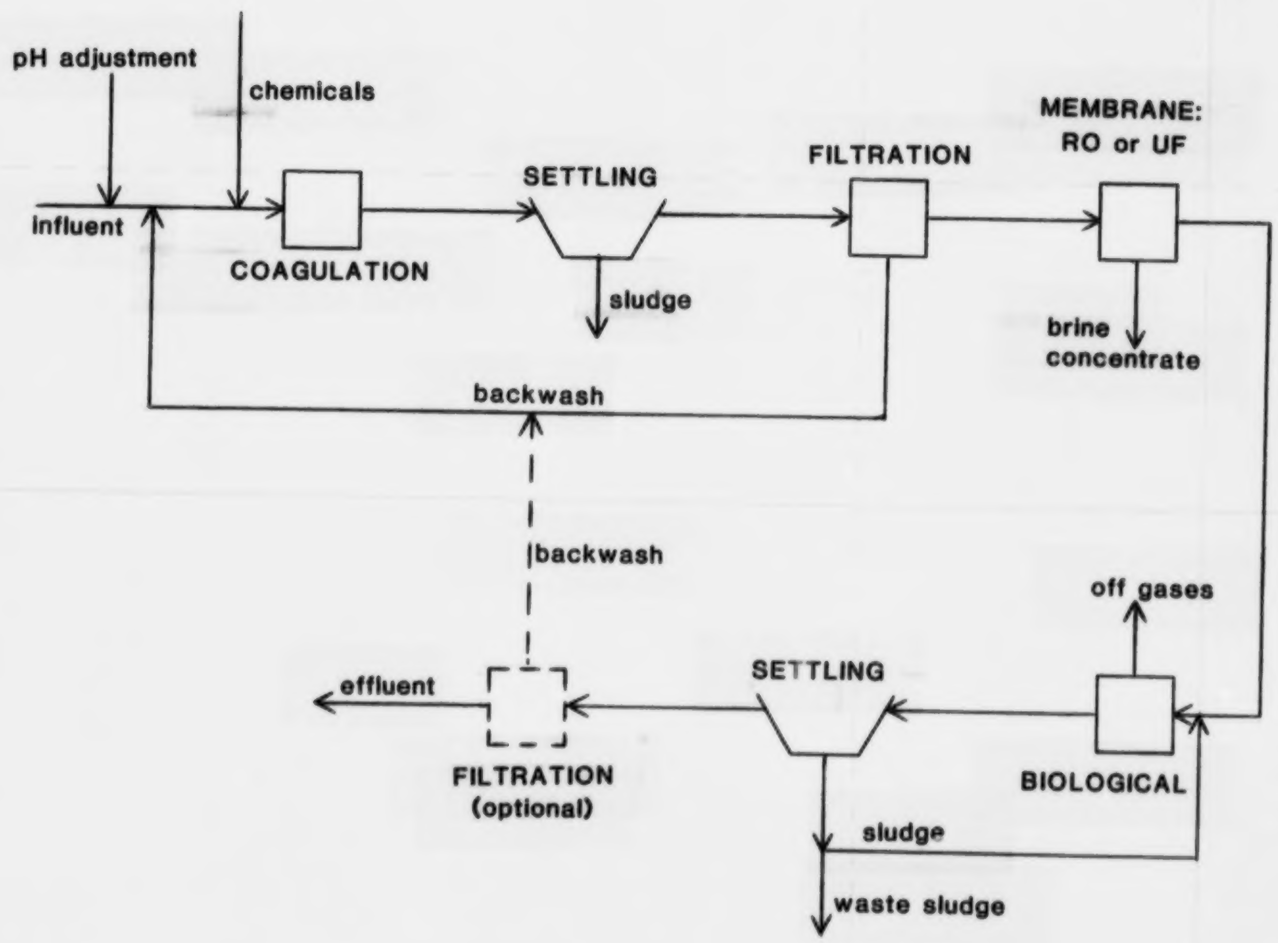

Figure 4. Schematic of membrane/biological process train.

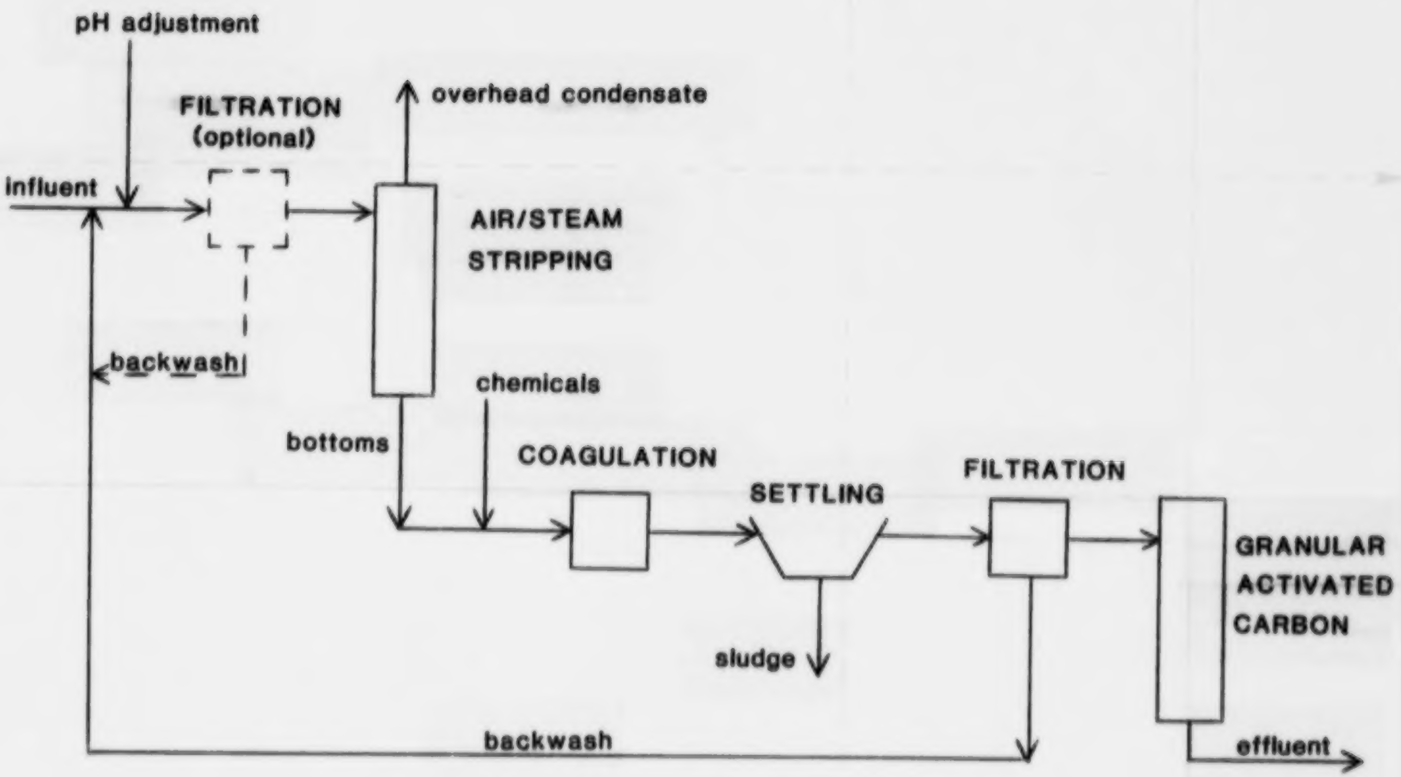

Figure 5.   Schematic of stripping/carbon sorption process train.

air-strippable compounds, air stripping may not be the best selection if air pollution is of potential concern; unless offgases can be contained and collected.

As previously discussed, stripping probably will remove biodegradable rather than refractory TOC. Therefore, it has been paired with activated carbon adsorption rather than a biological process.

Aside from pH adjustment prior to stripping, little pretreatment is necessary. If the wastewater contains readily settleable suspended solids, removal before packed column or tray tower steam stripping will prevent solids build-up in the stripping unit.

In addition to carbon treated effluent, this process train generates three waste streams: overhead condensate, chemical sludge, and spent carbon. Assuming that carbon will be regenerated, either on-site or by a commerical service, the two remaining streams require additional treatment and/or disposal. Preferably, the organic phase of the overhead condensate can be recovered and reused, with the water phase returned to the treatment system. However, if this is not possible, incineration is the best method for condensate disposal. Chemical sludge should be dewatered and disposed by a method commensurate with the materials contained in the sludge.

Process trains illustrated in Figures 1 through 5 do not represent the only possible configurations. They do, however, encompass the concentration technologies which are expected to have greatest broad range applicability and effectiveness. They also are the processes which have been demonstrated to some degree for treatment of hazardous aqueous wastewaters.

EVALUATION OF PROCESS TRAINS

Prior to initiating experimental studies, it was decided to perform a desktop evaluation of the five processes in an attempt to predict performance potential on actual hazardous waste streams. In order to select waste streams for this evaluation, a matrix was devised to group waste streams identified in Table B-1 according to the concentration of inorganic and organic constituents. This matrix shown in Figure 6 describes the concentration of the inorganic and organic constituents as high, medium, and low. In general, the working definitions of "high", "medium" and "low" are as follows:

		INORGANICS CONCENTRATION		
		High	Medium	Low
ORGANICS CONCENTRATION	High	Sites 006 011	Site 010	Sites 001 002 003 005 021 023 024 025 026 027
	Medium	Site 022		Sites 008 009 013
	Low	Sites 004 012 014 015 016 018		

Figure 6. Waste stream categorization matrix.

	Hazardous Inorganic Constituent	Hazardous Organic Constituent
High	greater than 5 times water quality criteria*	greater than 400 ppb
Medium	from 2 to 5 times water quality criteria*	from 5 to 400 ppb
Low	less than water quality criteria*	less than 5 ppb

In addition, if a gross parameter such as BOD or TOC was reported in significant concentration (BOD >20 mg/l; TOC >10 mg/l), the waste stream was considered to fall in the high organic category. Although this system is not rigorous, it does permit a useful grouping of the actual waste streams. Inspection of the matrix revealed that most of the actual waste streams identfied fell into one of two categories: high organic-low inorganic or low organic-high inorganic. With regard to the latter category, concentration technology is essentially state-of-the-art. Therefore, the low organic-high inorganic category was not considered further.

Waste stream data from Site 026 in the high organic-low inorganic category was selected for the evaluation for several reasons: the data set was one of the most comprehensive available; ongoing activity at the site foretold future supplemental data availability; the state had assumed responsibility for mitigation of contaminated groundwater problems; no litigation was involved; the state regulatory agency was cooperative; and a strong possibility existed for use of the actual waste in subsequent laboratory studies.

The second waste stream composition selected for the analysis was that of Site 010 in the high organic-medium inorganic category. Reasons for selection were similar to those given for Site 026. In addition, heavy metals were present. Thus, this waste stream is sufficiently different than that of Site 026 to provide a second case.

The third waste stream utilized is a hypothetical leachate postulated on the basis of data contained in another report (137). Frequency of occurrence of the various classes of chemicals given previously also was considered in formulating the hypothetical leachate. The postulated leachate composition represents the high organic-high inorganic case. Reasons for selecting a hypothetical leachate include: (1) it provides a common basis for testing the appropriateness of various technologies, (2) it represents a reproducable "waste" composition for potential use in laboratory studies, (3) it contains a limited number of constituents representative of the broad range of materials found at actual sites, and (4) it is representative of "average" conditions at numerous sites.

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* water quality criteria derived from Quality Criteria for Water, U.S. E.P.A., Washington, DC, July, 1976

Having selected waste streams for the evaluation, the next step entailed establishing effluent quality objectives for discharge to a receiving stream. Since established effluent limitation guidelines did not exist for the wastes of concern, the following procedure was utilized to define treatment objectives:

1. Where published, industrial effluent limitation guideline documents specified a numerical criteria for constituents present in the waste of concern, these criteria were applied. Criteria generally were available for pH, BOD, COD, SS, oil and grease, phenol, cyanide, and several heavy metals.

2. When only Interim Primary Drinking Water Standards or numerical water quality based criteria were available, these were used, but the effluent objective was set at an order of magnitude greater than the water quality criteria. This allows for the impact of dilution and is consistent with a tenfold factor originally proposed in the RCRA regulations related to leachate quality. For parameters where this tenfold multiplier was applied, a maximum effluent limitation of 1 mg/l was established on the basis that existing technologies could achieve this level. Utilizing this approach, limits were developed for certain metals and several pesticides.

3. Subsequent to the application of items 1 and 2 above, only the priority and non-priority specific organic constituents remained. The following two approaches were used for these:

    a. For non-priority organics, no effluent limitation was specified; the TOC limitation was the overriding limit.

    b. For organic priority pollutants, 99.9% reduction was deemed to be achievable and desirable. If achieving 99.9% reduction required removal to less than current analytical limits of detection, the detection limit was specified as the effluent objective.

Quantitative data on the three waste streams of interest together with the defined effluent objectives are given in Tables 4-6.

TABLE 4 WASTEWATER CHARACTERIZATION - SITE 010

Parameter	Raw Wastewater Composition Range **	Effluent Quality Objective **
pH	5.6 - 6.9 units	5 - 9 units
TOC	1800 - 4300 mg/l	20 mg/l
SOC	4200 mg/l	20 mg/l
COD	5900 - 11,500 mg/l	50 mg/l
Oil & Grease	90 mg/l	10 mg/l
SS	200 - 430 mg/l	10 mg/l
TDS	15,700 mg/l	No increase
SO_4	240 mg/l	250 mg/l
Sulfide	<0.1 mg/l	0.3 mg/l
Total P as P	<0.1 - 3.2 mg/l	0.1 mg/l
PO_4 as P	<0.1 mg/l	0.1 mg/l
TKN	5.4 mg/l	No limit
NH_4-N	0.65 mg/l	0.5 mg/l
NO_3-N	<0.1 mg/l }	
NO_2-N	<0.1 mg/l	10 mg/l
Na	1000 mg/l	No limit
Ca	2500 mg/l	No limit
Cl	9500 mg/l	No increase
Fe	31 - 330 mg/l	1 mg/l
Hg*	<0.5 - <1	20
Pb*	0.3 - 0.4 mg/l	0.50 mg/l
Sb*	2	200
As*	130	500
Cd*	11	100
Cr*	270	200
Cu	540	250
Ni*	240	250
Se*	9	100
Ag*	1	20
Zn*	480	2 mg/l
CN*	<0.01 mg/l	0.25 mg/l
Hexachlorobutadiene*	109	10^3 reduction
1,2,4-Trichlorobenzene*	23	<0.09
Aldrin*	<10	<1
Heptachlor*	573	<1
Phenol*	30	500
Phenols (total)*	3.5 mg/l	NS
2,4-Dichlorophenols*	10	<0.1
Methylchloride*	180	<0.4
1,1-Dichloroethylene*	28	<2.0
Chloroform*	ND - 4550	10^3 reduction
Trichloroethylene*	ND - 760	10^3 reduction
Dibromochloromethane*	ND - 35	<0.3
1,1,2,2-Tetrachloroethylene	ND - 1000	see TOC

TABLE 4 WASTEWATER CHARACTERIZATION - SITE 010 (cont.)

Parameter	Raw Wastewater Composition Range **	Effluent Quality Objective **
Chlorobenzene*	1200	10^3 reduction
Methanol	42.4 mg/l	see TOC limitation
Ethanol	56.4 mg/l	see TOC limitation
Acetone	50.3 mg/l	see TOC limitation
Isopropyl alcohol	<0.1 mg/l	see TOC limitation
Benzene*	ND - 3300	10^3 reduction
Toluene*	ND - 31,000	10^3 reduction
1,1,1-Trichloroethane*	ND - 225	<2
Carbon tetrachloride*	92	<4
Hexachlorocyclohexane-*		see TOC limitation
Alpha isomer	ND - 600	
Beta isomer	ND - 700	
Gamma isomer	ND - 600	
Delta isomer	ND - 120	

Footnotes:

* - A priority pollutant
** - All concentrations in µg/l, except as noted
ND - Not Detected

TABLE 5 WASTEWATER CHARACTERIZATION - SITE 026

Parameter	Raw Wastewater Composition Range **	Effluent Quality Objective **
pH	11.5	5 - 9
COD	5400 mg/l	50 mg/l
TOC	1500 mg/l	20 mg/l
NH_3-N	64 mg/l	0.5 mg/l
Organic N	110 mg/l	NL
Chloride	3800 mg/l	No increase
Conductivity	18,060 µmhos/CM	NL
SS	100 mg/l	10 mg/l
TDS	12,000 mg/l	No increase
Volatile Organics:		
Vinyl chloride*	140 - 32,500	10^3 reduction
Methylene chloride*	<5 - 6570	10^3 reduction
1,1-Dichloroethylene*	220 - 19,850	10^3 reduction
1,1-Dichloroethane*	<5 - 14,280	10^3 reduction
1,2-Dichloroethane*	350 - 8150	10^3 reduction
Benzene*	6 - 7370	10^3 reduction
1,1,2-Trichloroethane*	<5 - 790	10^3 reduction
1,1,2,2-Tetrachloroethane*	<5 - 1590	10^3 reduction
Toluene*	<5 - 5850	10^3 reduction
Ethyl benzene*	<5 - 470	10^3 reduction
Chlorobenzene*	<5 - 78	0.2
Trichlorofluoromethane*	<5 - 18	2.0
Acid Extractable Organics:		
o-Chlorophenol*	<3 - 20	0.09
Phenol*	<3 - 33	0.5 mg/l
o-sec-Butylphenol***	<3 - 83	see TOC limitation
p-Isobutylanisol*** or		
p-Acetonylanisol***	<3 - 86	see TOC limitation
p-sec-Butylphenol***	<3 - 48	see TOC limitation
p-2-oxo-n-Butylphenol	<3 - 1357	see TOC limitation
m-Acetonylanisol***	<3 - 1546	see TOC limitation
Isoprophylphenol***	<3 - 8	see TOC limitation
1-Ethylpropylphenol	<3	see TOC limitation
Dimethylphenol*	<3	0.01
Benzoic acid	<3 - 12,311	see TOC limitation

TABLE 5 WASTEWATER CHARACTERIZATION - SITE 026 (cont.)

Parameter	Raw Wastewater Composition Range **	Effluent Quality Objective **
Base Extractable Organics:		
Dichlorobenzene*	<10 - 172	10^3 reduction
Dimethylaniline	<10 - 6940	see TOC limitation
m-Ethylaniline	<10 - 7640	see TOC limitation
1,2,4-Trichlorobenzene*	<10 - 28	0.09
Naphthalene*	<10 - 66	10^3 reduction
Methylnapthalene	<10 - 290	see TOC limitation
Camphor	<10 - 7571	see TOC limitation
Chloroaniline	<10 - 86	see TOC limitation
Benzylamine or o-Toluidine	<10 - 471	see TOC limitation
Phenanthrene* or Anthracene*	<10 - 670	10^3 reduction

Footnotes:
* - A priority pollutant
** - All concentrations in μg/l except as noted
*** - Structure not validated by actual compound
NL - No effluent limitation

TABLE 6 WASTEWATER CHARACTERIZATION - SYNTHETIC LEACHATE

Parameter	Raw Wastewater Composition Range (mg/l)	Effluent Quality Objective (mg/l)
TOC	500	20
BOD	1000	30
COD	1400	50
pH	5.0	5 - 9
Cl	285	No increase
NH_4^+	50	0.5
SS	50	10
TDS	350	No increase
Na	113	NL
Ca	110	NL
Mg	50	NL
K	10	NL
Fe^{+2}	10	1.0
Mn	1.0	1.0
As^{+5}*	20	0.5
Ba	2.0	1.0
Cr^{+3}*	0.5	0.2 (Total Cr)
Se*	0.5	0.1
Cu*	5.0	0.25
Ni*	0.5	0.25
Zn*	5.0	2.0
Cd*	1.0	0.1
Hg*	0.1	0.02
CN*	1.0	0.25
Phenol*	10	0.5
Trichloroethylene*	2.0	10^3 reduction
Ethanol	50	see TOC limitation
Acetone	100	see TOC limitation
Benzene*	5.0	10^3 reduction
o-Chlorobenzene*	1.0	10^3 reduction
o-Nitrophenol*	2.0	10^3 reduction
Endrin*	10 ppb	<1 ppb

Footnotes:
* - A priority pollutant

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Based upon the unit process performance data compiled from the literature, the performance potential of each of the five process trains was calculated for each of the waste streams. These calculations indicated that all of the process trains were potentially capable of meeting the established effluent quality objectives for stream discharge. However, because much of the available data were generated from single compound, laboratory scale studies, actual treatability of a multi-component wastewater cannot be accurately stated without conducting treatability studies using the actual wastewaters. This point was stressed by various company representatives marketing concentration technology treatment equipment/products. In general, vendors would not provide either performance estimates or process sizing and cost estimates (at ±30% levels) without conducting treatability studies even though it would be expected that they would possess the best data for making these estimates. Thus, while the most promising concentration technologies and process trains can and have been identified, subsequent treatability studies are necessary to verify performance expectations, and to select the optimum process train for a particular situation.

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APPENDIX A

This appendix identifies entities queried with regard to data on hazardous aqueous waste problems, waste stream composition, and concentration technology applications and effectiveness.

TABLE A-1

ENTITIES CONTACTED

	Location
Environmental Protection Agency	
Region I	Boston, MA
Region II	New York, NY
Region III	Philadelphia, PA
Region IV	Atlanta, GA
Region V	Chicago, IL
Region VII	Kansas City, MO
Region IX	San Francisco, CA
Region X	Seattle, WA
IERL	Cincinnati, OH
MERL	Cincinnati, OH
Office of Solid Wastes	Washington, DC
Oil and Hazardous Materials Spills Branch	Edison, NJ
National Enforcement Investigations Center	Denver, CO
Federal Agencies	
U.S. Army Toxic and Hazardous Materials Agency	Aberdeen, MD
Rocky Mountain Arsenal	Commerce City, CO
Redstone Arsenal	Huntsville, AL
Bureau of Reclamation	Boulder City, NV
U.S. Geological Survey	Menlo Park, CA
State Agencies	
California	Sacramento, CA
Connecticut	Hartford, CT
Georgia	Atlanta, GA
Illinois	Champaign, IL

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TABLE A-1 (continued)

	Location
State Agencies	
Kentucky	Frankfort, KY
Louisiana	Baton Rouge, LA
Maine	Bangor, ME
Massachusetts	Boston, MA
Michigan	Lansing, MI
Minnesota	St.Paul, MN
Nevada	Carson City, NV
New Jersey	Trenton, NJ
New York	Albany, NY
Ohio	Columbus, OH
Pennsylvania	Harrisburg, PA
	Pittsburgh, PA
	Norristown, PA
	Reading, PA
Texas	Austin, TX
Virginia	Richmond, VA
West Virginia	Charleston, WV
Others	
City of Niagara Falls	Niagara Falls, NY
Gloucester County Planning Commission	Clayton, NJ
Companies	
ABCOR	Wilmington, MA
AMOCO	Chicago, IL
Calgon Corp.	Pittsburgh, PA
Carborundum Co.	Niagara Falls, NY
Chem-Bac Environmental Systems	Pittsburgh, PA
FMC	Princeton, NJ
ICI Americas Inc.	Wilmington, DE
Ionics Inc.	Watertown, MA
Matlack Trucking Company	Swedesboro, NJ
O & H Materials Inc.	Findlay, OH
Osmonics Inc.	Hopkins, MN
Permutit Co.	Paramus, NJ
Resources Conservation Company	Seattle, WA
Rohm & Haas	Philadelphia, PA
Westvaco	Covington, VA

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APPENDIX B

Appendix Table B-1 contains data on identified hazardous waste problems and to the extent possible data on waste composition. A reference list which indicates data sources and pertains only to this table follows the main body of the table.

Problem sites are identified by a code number in Table B-1. The code numbers and associated problem sites are listed below.

Site Number	Site Description
001	Helevia Landfill adjacent to West Omerod water supply (near Allentown, PA)
002	Haverford, PA
003	Centre County, PA (near State College, PA)
004	Stringfellow Landfill, Riverside, CA
005	Rocky Mountain Arsenal, Commerce City, CO
006	Geological Reclamation Operations and Waste Systems, Inc. (GROWS) landfill, Falls Township, PA
007	Wade Site, Chester, PA
008	Bridgeport Quarry, Montgomery County, PA
009	Redstone Arsenal, Huntsville, AL
010	Love Canal, Niagara Falls, NY
011	LaBounty Dump Site, Charles City, IA
012	Saco Landfill, Saco, ME
013	Whitehouse, FL
014	near Myerstown, PA
015	Undisclosed
016	Necco Park, Niagara Falls, NY
017	FMC, Middleport, NY
018	Frontier Chemical Waste Process Inc., Pendleton, NY
019	102nd Street, Niagara Falls, NY
020	Pfohl Brothers, Buffalo, NY
021	Reilly Tar & Chemical Co., St.Louis Park, MN
022	Windham Landfill, Windham, CT
023	LiPari Landfill, Gloucester County, NJ
024	Kin-Buc Landfill, Middlesex County, NJ
025	South Brunswick, NJ
026	Ott/Story site, Muskegon County, MI
027	Hooker Chemical Co., Montague, MI

TABLE B-1

SUMMARY OF REPORTED WATER CONTAMINATION PROBLEMS

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Halocarbons	001	Between 1968 and 1969 landfill accepted various liquid industrial wastes at rate of 3,000 gal/wk; about 25 to 30% trichloroethylene (TCE)*. Materials percolated from excavated basin which now is under 50 to 60 ft of fill. Other wastes included ethyl acetate and phenols. TCE* in ground water within plume - 191 to 260 mg/l TCE* in ground water, ¼ mi downgradient of site - 15 to 20 mg/l	1
Phenols	002	Pentachlorophenol (PCP)* laden oil was deep well injected and later appeared in ground water and streams. EPA carbon trailer used to treat limited amount of contaminated ground water. PCP* in ground water a few hundred feet down gradient of injection point - 2.4 mg/l	2,3
Pesticides	003	Industrial waste containing Kepone and Mirex both spray irrigated and "Chemfixed" and placed in impoundments. Fixing held metals but promoted release of pesticides. Kepone in stream - 2 mg/l	4
Metals Pesticides Misc.	004	Site included impoundments for liquid industrial wastes and storage of solid industrial wastes. Acids, plating wastes, and DDT were major materials disposed of although wide	5 (continued)

TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Metals Pesticides Misc. (continued)		variety of materials went to site. Leachate known to exist. Soil and down stream surface water affected; area of groundwater contamination plume unknown. Surface water quality downstream of site (range): Cd* - 4.8 - 8.2 mg/l Cr* - 52 - 205 mg/l Cu* - 7 - 16 mg/l Mn - 340 - 550 mg/l Ni* - 28 - 48 mg/l Zn* - 77 - 115 mg/l pH - ∿3	
Aliphatics Halocarbons Pesticides Polynuclear Aromatics Metals	005	Groundwater contamination resulting from the impoundment of demilitized warfare agents and wastes from chemical production facility. Efforts underway to treat contaminated groundwater. Quality of contaminated groundwater (range): aldrin* - <2 µg/l dieldrin* - <2 - 4.5 µg/l dicyclopentadiene - 80 - 1,200 µg/l diisopropylmethylphosphonate - 400 - 3,600 µg/l p-chlorophenylmethyl-sulfide - <10 - 68 µg/l p-chlorophenylmethyl-sulfoxide - <10 - 53 µg/l p-chlorophenylmethyl-sulfone - <10 - 40 µg/l endrin* - <2 - 9 µg/l Nemagon - <1 - 8 µg/l The following are averages (all as mg/l): Al - 0.124 Ba - 0.1 Be* - 0.007 As* - 0.011 Bo - 0.624 Ca - 164	6 (continued)

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY			REFERENCE
Aliphatics Halocarbons Pesticides Polynuclear Aromatics Metals (continued)		Co - 0.1 Cr* - 0.012 Cu* - 0.001 Fe - 0.090 Pb* - 0.001 Mg - 49.4 Mn - 1.04 Mo - 0.114 Ni* - 0.032 K - 6.83	Se* - 0.003 Na - 378 Zn* - 0.024 Hg* - 0.0002 TKN - 2.22 NO_2-N - <0.010 NO_3-N - <0.012 NH_3-N - <0.010 Total P - 1.39	PO_4-P - <0.010 TOC - 10.9 Total inorganic carbon - 71 SO_4 - 505 Cl - 420 pH - 7.6 COD - 24.6 SS - 10.4 TDS - 1830	
Metals Misc.	006	Landfill accepts municipal and industrial residues; leachate with following average quality is produced (mg/l): BOD - 10,900 COD - 18,600 SS - 1,040 TDS - 13,000 pH - 6.85 Alkalinity, as $CaCO_3$ - 5,400 Hardness, as $CaCO_3$ - 4,650 Ca - 818 Mg - 453 PO_4 - 2.74 NH_3-N - 1000		TKN - 984 SO_4 - 462 Cl - 4,240 Na - 1,350 K - 961 Cd* - 0.086 Cr* - 0.28 Fe - 312 Ni* - 1.55 Pb* - 0.67 Zn* - 21 Hg* - 0.007	7

(continued)

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Aromatics Phenols Phthalates Polynuclear Aromatics Amines Misc.	007	Hazardous wastes stored in drums and tanks on site. Following contaminants were found in soil and puddles of liquid at site: 1,4-dichlorobenzene* 1,2-dichlorobenzene* 1,2,4-trichlorobenzene* tetrachlorobenzene isomer dibutylphthalate* methylnaphthalene isomer methyoxyphenol isomer isophorone* naphthalene* diphenylamine* dimethylnaphthalene isomer 1-chloro-3-nitrobenzene fluoranthene* phenanthrene* 3-ethyltoluene 1,3,5-trimethylbenzene 1,2,4-trimethylbenzene 1,2,3-trimethylbenzene	8
Halocarbons	008	Following contaminants were detected in groundwater possibly due to migration from upgradient impoundment disposal site: 1,1,1-trichloroethane* - 1.6 - 2.8 μg/l trichloroethene - 6.9 - 16 μg/l dichloropropene* - detected, not quantified	9

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Pesticides	009	Isomers of DDT present in surface waters downstream of pesticide production facility. Efforts underway to treat surface waters. DDT* - ranged from 4.28 to 14.26 μg/l with average of 11.36 μg/l (over 3 months in 1979)	10
Aromatics Halocarbons Metals Misc. Phenols	010	Following contaminants were detected leaching from an inactive disposal site used by a chemical producer (concentrations in mg/l, except as noted): pH - 5.6 - 6.9 Na - 1000 TOC - 1800 - 4300 Ca - 2500 SOC - 4200 Cl - 9500 COD - 5900 - 11,500 Fe - 31 - 330 Oil & Grease - 90 Hg* - <0.0005 - <0.001 SS - 200 - 430 Pb* - 0.3 - 0.4 TDS - 15,700 Sb* - 2 μg/l** $SO_4^=$ - 240 As* - 130 μg/l** $S^=$ - <0.1 Cd* - 11 μg/l** Total P as P<0.1 - 3.2 Cr* - 270 μg/l** PO_4 as P - <0.1 Cu* - 540 μg/l** TKN - 5.4 Ni* - 240 μg/l** NH_4-N - 0.65 Se* - 9 μg/l** NO_3-N - <0.1 Ag* - 1 μg/l** NO_2-N - <0.1 Zn* - 480 μg/l** Cn* - <0.01 hexachlorobutadiene* - 109 μg/l** 1,2,4-trichlorobenzene* - 23 μg/l** aldrin* - 23 μg/l** heptachlor* - <10 μg/l**	12 22 27 28

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Aromatics Halocarbons Metals Misc. Phenols (continued)		phenol* - 30 μg/l**	
		phenols (total)* - 4.5**	
		2,4-dichlorophenols* - 10 μg/l**	
		methyl chloride* - 180 μg/l**	
		1,1-dichloroethylene - 28 μg/l	
		chloroform* - ND - 4550 μg/l	
		trichloroethylene* - ND - 760 μg/l	
		dibromochloromethane* - ND - 35 μg/l	
		1,1,2,2-tetrachloroethylene - ND - 1000 μg/l	
		chlorobenzene* - 1200 μg/l**	
		methanol - 42.4**	
		ethanol - 56.4**	
		acetone - 50.3**	
		isopropyl alcohol - <0.1**	
		benzene* - ND - 3300 μg/l	
		toluene* - ND - 31,000 μg/l	
		1,1,1-trichloroethane* - ND - 225 μg/l	
		carbon tetrachloride* - 92 μg/l**	
		hexachlorocyclohexane*	
		alpha isomer - ND - 600 μg/l	
		beta isomer - ND - 700 μg/l	
		gamma isomer - ND - 600 μg/l	
		delta isomer - ND - 120 μg/l	
		** denotes concentration following flow equalization and sand filtration processes and prior to granular carbon adsorption	
			(continued)

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Metals Aromatics Halocarbons Misc. Phenols Polynuclear Aromatics	011	Groundwater reported to be contaminated by migration of pollutants from municipal landfill utilized by pharmaceutical manufacturer for disposal of production residues. Following data represents groundwater quality at well located between landfill and river which is downgradient. Other wells in area and downstream also report contamination (concentrations in µg/l, except as noted): BOD - 2000 mg/l COD - 7100 mg/l TOC - 2300 mg/l TSS - <3 mg/l Total Phenols - 18 mg/l NH-N - 130 mg/l As* - 590 mg/l Ba - 0.60 mg/l Cu* - 0.02 mg/l Hg* - 0.0048 mg/l Zn* - 0.17 mg/l	13 14

Volatile Organics:	range	average
benzene*	150 - 230	190
chlorobenzene*	4.6 - 7.0	5.5
1,2-dichloroethene*	270 - 330	310
trans-1,2-dichloroethene*	25 - 31	28
dichloromethane*	29 - 130	82
ethyl benzene*	3.0 - 5.2	3.9
toluene*	24 - 34	28
1,1,1-trichloroethane*	4.2 - 5.6	5.0
1,1.2-trichloroethane*	390 - 870	600
trichloromethane*	90 - 320	250
trichloroethane*	39 - 48	43
tetrachloroethylene*	-	23
Neutral Extractible Organics:		
aniline	140 - 870	410

(continued)

TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY			REFERENCE
Metals Aromatics Halocarbons Misc. Phenols Polynuclear Aromatics (continued)		Neutral Extractible Organics (continued):	range	average	
		o-chloroaniline	ND - 360	140	
		p-chloronitrobenzene	460 - 940	720	
		chloronitrotoluene	ND - 460	120	
		4-chloro-3-nitrobenzamide	440 - 8700	4200	
		2,6-dichlorobenzamine	890 - 30,000	8800	
		2-ethylhexanal	ND - 4500	2600	
		2-ethylhexanol	19,000 - 23,000	22,000	
		3-heptanone	ND - 1300	640	
		phenol*	12,000 - 17,000	14,000	
		o-nitroaniline	170,000 - 180,000	180,000	
		p-nitroaniline	32,000 - 47,000	37,000	
		nitrobenzene*	ND - 740	250	
		o-nitrophenol*	8,600 - 12,000	11,000	
		2-chlorophenol*	-	3	
		2,4-dinitrophenol*	-	99	
		n-nitrosodiphenylamine* as diphenylamine	-	190	
		1,1-dichloroethylene*	-	P	
Metals Misc.	012	Following contaminants detected in groundwater at well near tannery sludge disposal area: Cr* - 1 mg/l average; 5 mg/l maximum Zn* - 2.77 mg/l average; 4.9 mg/l maximum pH - 6.35 average; 6.0 minimum			15
					(continued)

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
PCB's	013	Impoundments containing PCB contaminated oil and water were dewatered to eliminate threat of stream and groundwater pollution. Influent to powdered activated carbon treatment facility contained: Aroclor 1242* Aroclor 1254* ranged from 0.56 to 7.7 μg/l Aroclor 1260*	16
Metal	014	Groundwater contamination resulted from land disposal of arsenic compounds by pharmaceutical manufacturer. Prior to installation of groundwater purging and treatment system, arsenic* concentrations were 10,000 mg/l; after several years of purging concentrations of 10-30 mg/l remain.	17
Metal	015	Waste aresenic was disposed of in dump. Arsenic* concentrations found in groundwater were 175 mg/l.	17
Metals	016	Following contaminants found in groundwater near inactive chemical waste disposal site: Ba - 2000 mg/l Other inorganics and organics anticipated to be present.	18
Metals Pesticides	017	Arsenic* and Carbofuran found in surface runoff and in lagoon used by chemical manufacturer.	18
			(continued)

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Metals Misc.	018	Following contaminants found in impoundment used by chemical waste processor (conc. in mg/1): Cd* - 1 Cu* - 9 Fe - 60 Ni* - 3 Zn* - 1 pH - 3 NH_3-N - 30	18
Metals Aromatics	019	Mercury* and benzene hexachloride believed to be in groundwater in vicinity of chemical manufacturing and waste disposal operations.	18
Aromatics	020	Chlorinated benzenes found in leachate and groundwater in vicinity of waste disposal operation used by several chemical producers.	18
Phenol Polynuclear Aromatics	021	Following contaminants found in shallow groundwater in vicinity of chemical production facility: phenol* - 50 μg/1 polynuclear aromatics - 3400 μg/1	19
Metals Misc.	022	Following range of contaminants were found in ground and surface waters (ponds) in vicinity of municipal landfill which also accepted industrial wastes (conc. in mg/1):	20

Pollutant	3 worst case wells	2 worst case surface waters
Alkalinity	20.6 - 300	81 - 156
pH	6.27 - 6.5	6.22 - 6.3

(continued)

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY			REFERENCE
Metals Misc. (continued)		Pollutant	3 worst case wells	2 worst case surface waters	
		TS	840 - 1730	159 - 258	
		TOC	12 - 39	20.4 - 33.5	
		TKN	<1 - 8.7	6.05	
		Cl	31.0 - 125	3.65 - 7.48	
		Na - mixed/settled[a]	4.6 - 34.1/26.9	21.5 / NR	
		Mn - mixed/settled[a]	0.41 - 4.16/3.70	1.03 / NR	
		Fe - mixed/settled[a]	21.1 - 196/162	3.38 / NR	
		Zn*- mixed/settled[a]	0.32 - 0.54/0.21	0.07 / NR	
		Cu*-mixed/settled[a]	0.082 - 0.365/0.076	0.006 / NR	
		Pb*-mixed/settled[a]	0.196 - 0.393/0.271	0.003 / NR	
		Cr*-mixed/settled[a]	0.123 - 0.55/0.28	<0.001 / NR	
		Specific conductance	80 - 1200	NR	
		a - results reported for mixed sample and supernatant from settled sample NR - not reported			
Metals Phenols Misc.	023	Following contaminants were detected in groundwater downgradient of landfill which accepted large quantities of pharmaceutical wastes. Data represents quality range at 3 poorest quality wells over 2 yr time span. (conc. as mg/l):			21

pH	6.0 - 7.9	Cl	40 - 1500
specific conductance	180 - 2000	F	0.14 - 1.3
temperature (^{o}F)	58 - 63	TDS	1455
color	50 - 4000	NO_3-N	0.01 - 0.04
sulfate	1.2 - 25	PO_4-P	0.04
total hardness	700 - 1700	Fe	0.21 - 678
Ca	180 - 280	K	4.9 - 30
Mg	25 - 250	Mn	0.01 - 1.0

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Metals Phenols Misc. (continued)		Na 13 - 130 CN* 0.005 Se * 0.01 - 0.02 Pb* 0.10 COD 168 - 9920 Cu* 0.10 - 0.71 BOD_5 42 - 4040 Hg* 0.0005 MBAS 0.24 Zn* 0.36 - 26.8 Phenols* 0.008 - 54.17 Ag* 0.01	
Aromatics Halocarbons PCB's Polynuclear Aromatics Phthalates	024	Following range of contaminants WAS detected in leachate from landfill accepting major proportions of chemical production wastes (conc. in µg/l, except as noted): Aroclor 1254* 70 Aroclor 1016*/1242* 110 to 1900 Aroclor 1016*/1242*/1254* 66 to 1.8 g/l benzene* P to 1930 biphenyl napthalene P chlorobenzenes* P to 4620 camphene P C_4 alkyl cyclopentadiene P C_5 substituted cyclopentadiene P dichlorobenzene* P to 517 dichloroethane* 180 dichloroethylene P limonene P methyl chloride* 3.1 methyl napthalene P parafins P petroleum oil P phthalates P phthalate esters P pinene P	23 (continued)

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY		REFERENCE
Aromatics Halocarbons PCB's Polynuclear Aromatics Phthalates (continued)		styrene tetrachloroethylene* toluene* trichloroethane* trichloroethylene* trimethylbenzenes MIBK xylene	P P to 590 P to 16,200 P to 490 P to 7700 P 2000 P to 3300	
Halocarbons Misc.	025	Following contaminants were detected in groundwater in vicinity of municipal landfill due to "industrial waste seepage from landfill" (conc. in µg/l):		24
		1,1,1-trichloroethane* tetrachloroethylene* 1,1-dichloroethane* 1,2-dichloroethylene* chloroform* 1,2-dichloroethane* dibromochloromethane* bromoform* TOC	532 187 2.3 0.2 1.1 2.1 3.9 0.2 500	
Halocarbons Aromatics Phenols Polynuclear Aromatics	026	Ground and surface waters were polluted by migration of contaminants from waste disposal lagoons and direct discharge practices attributed to chemical production facility. Following data describe groundwater quality range at four wells located within the groundwater contamination plums (conc. in µg/l):		25

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Halocarbons Aromatics Phenols Polynuclear Aromatics (continued)		Volatile Organics:	
		vinyl chloride* 140 to 32,500	
		methylene chloride <5 to 6570	
		1,1-dichloroethylene* 220 to 19,850	
		1,1-dichlorethane* <5 to 14,280	
		1,2-dichlorethane* 350 to 8150	
		benzene* 6 to 7370	
		1,1,2-trichloroethane* <5 to 790	
		1,1,2,2-tetrachloroethane* <5 to 1590	
		toluene* <5 to 5850	
		ethylbenzene* <5 to 470	
		chlorobenzene* <5 to 78	
		trichlorofluoromethane* <5 to 18	
		Acid Extractable Organics:	
		o-chlorophenol* <3 to 20	
		phenol* <3 to 33	
		o-sec-butylphenol[b] <3 to 83	
		p-isobutylanisol[b] or p-acetonylanisol[b] <3 to 86	
		p-sec-butylphenol[b] <3 to 48	
		p-2-oxo-n-butylphenol <3 to 1357	
		m-acetonylanisol[b] <3 to 1546	
		isoprophylphenol[b] <3 to 8	
		1-ethylpropylphenol <3	
		dimethylphenol* <3	
		benzoic acid <3 to 12,311	
		Base Extractible Organics:	
		dichlorobenzene* <10 to 172	
		dimethylaniline <10 to 6940	(continued)

TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY	REFERENCE
Halocarbons Aromatics Phenols Polynuclear Aromatics (continued)		Base Extractible Organics (continued): m-ethylaniline <10 to 7640 1,2,4-trichlorobenzene* <10 to 28 napthalene* <10 to 66 methylnapthalene <10 to 290 camphor <10 to 7571 chloroaniline <10 to 86 benzylamine or o-toluidine <10 to 471 phenanthrene* or anthracene* <10 to 670 b - structure not validated by actual compound	
Halocarbons Aromatics Misc.	027	Groundwater pollution caused by the production, disposal, and storage of chemicals and waste residues in vicinity of chemical production facility (conc. in µg/l, except as noted): chloride 5.5 to 8000 mg/l tetrachloromethane* <1 to 25,000 trichloromethane* <1 to <10,000 trichloroethene <3 to 10,000 tetrachloroethene <1 to >50,000 hexachlorobutadiene* (^{C}46) <20 hexachlorocyclopentadiene* (^{C}56) <100 octachlorocyclopentene (^{C}58) <100 hexachlorobenzene* (^{C}66) <100	26
Metals Misc.	Compilation of sites	Pollutants found to be present in leachates based upon examination of 43 landfills which accept industrial wastes:	11 (continued)

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TABLE B-1 (continued)

CONTAMINANT CLASSIFICATION	SITE CODE	PROBLEM DESCRIPTION AND WATER QUALITY				REFERENCE
		Pollutant	Conc. Range (mg/l)	Typical Conc. (mg/l)	No. of Sites Where Detected	
Metals Misc. (continued)		As*	0.03 - 5.8	0.2	5	
		Ba	0.01 - 3.8	0.25	24	
		Cr*	0.01 - 4.20	0.02	10	
		Co	0.01 - 0.22	0.03	11	
		Cu*	0.01 - 2.8	0.04	15	
		CN*	0.005 - 14	0.008	14	
		Pb*	0.3 - 19	-	3	
		Hg*	0.0005 - 0.0008	0.0006	5	
		Mo	0.15 - 0.24	-	2	
		Ni*	0.02 - 0.67	0.15	16	
		Se*	0.01 - 0.59	0.04	21	
		Zn*	0.01 - 240	3.0	9	
		Light Organics	1.0 - 1000	80	10	
		Halogenated Organics	0.002 - 15.9	0.005	5	
		Heavy Organics	0.01 - 0.59	0.1	8	

* - A priority pollutant

ND - Not Detected

P - Present

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TABLE B-1 (continued)

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APPENDIX C

CHEMICAL TREATABILITY

Appendix Table C-1 presents information on the treatability of individual chemical compounds by various concentration technologies. Primary organization of the table is by concentration process. For each concentration process, the treatability of individual chemical compounds is given with the compounds arranged in alphabetical order within chemical calssifications. The following concentration processes are included:

Process	Process Code No.
Biological	I
Coagulation/Precipitation	II
Reverse Osmosis	III
Ultrafiltration	IV
Stripping	V
Solvent Extraction	VII
Carbon Adsorption	IX
Resin Adsorption	X
Miscellaneous Sorbents	XII

The chemical classification system used is described in the body of this report; the following chemical classes are used in Appendix C:

Chemical Classification	Classification Code No.
Alcohols	A
Aliphatics	B
Amines	C
Aromatics	D
Ethers	E
Halocarbons	F
Metals	G
PCBs	I
Pesticides	J
Phenols	K
Phthalates	L
Polynuclear Aromatics	M

In order to present the large quantity of information in a concise manner, it was necessary to code some of the information. The coding system is explained in footnotes at the end of

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Table C-1.

Many chemical compounds are known by several names. Attempts were made to use preferred or generic names according to The Merck Index. However, in some cases it was necessary to use the names which were used in the reference documents. Users of Table C-1 are advised to check for compounds under several potential alphabetic listings.

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TABLE C-1 CHEMICAL TREATABILITY

Concentration Process: Biological Treatment (I)
Chemical Classification: Alcohols(A)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IA-1	n-Amyl Alcohol (1-Pentanol)	R			Toxic threshold to sensitive aquatic organisms (approx) >350 mg/l.		99
IA-2	Borneal	U	P		90.3% reduction based on COD; rate of biodegradation 8.9 mg COD/g hr.	Activated sludge process.	81
IA-3	Butanol	F	I		70-90% reduction.	Aerated lagoon treatment.	100
IA-4	Butanol	F	I		98% reduction w/80% BOD reduction.	Completely mixed activated sludge process.	101
IA-5	Butanol	R			Toxic threshold to sensitive aquatic organisms (approx) <250 ppm.		99
IA-6	Butanol	F	I	BOD load of 42 lb/day/1000 ft^3	95-100% reduction.	Activated sludge process.	56
IA-7	Butanol	U	P		98.8% reduction based on COD; rate of biodegradation 84 mg COD/g hr.	Activated sludge process.	81
IA-8	sec-Butanol	U	P		98.5% reduction based on COD; rate of biodegradation 55 mg COD/g hr.	Activated sludge process.	81
IA-9	tert-Butanol	U	P		95.5% reduction based on COD; rate of biodegradation 30 mg COD/g hr.	Activated sludge process.	81
IA-10	tert-Butanol	L	S		Substrate partially degraded.	Acclimated aerobic culture.	102

(continued)

TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IA-11	1,4-Butanediol	U	P		98.7% reduction based on COD; rate of biodegradation 40 mg COD/g hr.	Activated sludge process.	81
IA-12	Cyclohexanol	U	P		96% reduction based on COD; rate of biodegradation 28 mg COD/g hr.	Activated sludge process.	81
IA-13	Cyclopentanol	U	P		97% reduction based on COD; rate of biodegradation 55 mg COD/g hr.	Activated sludge process.	81
IA-14	Dimethylcyclohexanol	U	P		92.3% reduction based on COD; rate of biodegradation 21.6 mg COD/g hr.	Activated sludge process.	81
IA-15	1,2-Ethanediol	L	S	484 ppm	74-76% reduction of BOD in 24 hrs. 7.5% of TOD exerted in 24 hrs.	Pure aerobic culture.	103
IA-16	Ethanol	F	I		70-90% reduction.	Treated by aerated lagoon.	100
IA-17	Ethanol	L	U	1000 ppm	>99% reduction of BOD in 24 hrs. 24% of TOD exerted in 24 hrs.	Pure aerobic culture.	103
IA-18	Ethanol	F	I		95-100% reduction w/80% BOD reduction.	Completely mixed activated sludge process.	101
IA-19	Ethyl Butanol	F	I		30-50% reduction.	Treated by aerated lagoon.	100
IA-20	Ethyl Butanol	F	I		95-100% reduction w/80% BOD reduction.	Completely mixed activated sludge process.	101
IA-21	Ethyl Butanol	F	I	42 lb/day/ 1000 ft^3	75-85% reduction.	Activated sludge process.	56
IA-22	2-Ethylhexanol	F	I	42 lb/day/ 1000 ft^3	75-85% reduction.	Activated sludge process.	56

(continued)

TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IA-23	Furfuryl Alcohol	U	P		97.3% reduction based on COD; rate of biodegradation 41 mg COD/g hr.	Activated sludge process.	81
IA-24	Furfuryl Alcohol	U	P		96.1% reduction based on COD; rate of biodegradation 40 mg COD/g hr.	Activated sludge process.	81
IA-25	Hexanol	U	P		95-100% reduction.	Activated sludge process.	56
IA-26	1-Hexanol	F	I		70-90% reduction.	Treated by aerated lagoon.	100
IA-27	1-Hexanol	F	I		100% reduction w/80% BOD reduction.	Completely mixed activated sludge process.	101
IA-28	Isopropanol	F	I		70-90% reduction.	Treated by aerated lagoon.	100
IA-29	Isopropanol	F	I		96% reduction w/80% BOD reduction.	Completely mixed activated sludge.	101
IA-30	Isopropanol	L	S		100% reduction; acetone was intermediate where upon 50% reduced by bio-oxidation & 50% removed by air stripping	Acclimated aerobic culture.	102
IA-31	Isopropanol	U	P		99% reduction based on COD; rate of biodegradation 52 mg COD/g hr.	Activated sludge process.	81
IA-32	Isopropanol	U	P	BOD load of 42 lb/day/1000 ft^3	95-100% reduction.	Activated sludge process.	56

(continued)

TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Alcohols (A

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IA-33	Methanol	F	I	BOD load of 42 lb/day/1000 ft^3	75-85% reduction.	Activated sludge process.	56
IA-34	Methanol	F	I		30-50% reduction.	Treated by aerated lagoon.	100
IA-35	Methanol	L	U	997 ppm	2.4-5.7% reduction of BOD 24 hrs. 36 to 41 mg O_2 used in 24 hrs. 2.4 -1.7% of TOD exerted in 24 hrs.	Pure aerobic culture.	103
IA-36	Methanol	L	U	500 ppm	110 mg O_2 used in 24 hrs. 14.6% of TOD exerted in 24 hrs.	Pure aerobic culture.	103
IA-37	Methanol	F	I		84% reduction w/80% BOD reduction.	Completely mixed activated sludge.	101
IA-38	Methanol	F,C	I	170-2550 ppb	Effluent conc. of 150-510ppb achieved.	Survey of 2 municipal wastewater treatment plants.	65
IA-39	4-Methylcyclohexanol	U	P		94% reduction based on COD; rate of biodegradation 40 mg COD/g hr.	Activated sludge process.	81
IA-40	Octanol	F	I		75% reduction w/80% BOD reduction.	Completely mixed activated sludge.	101
IA-41	Octanol	F	I		30-50% reduction.	Treated by aerated lagoon.	100
IA-42	Pentarythritol	L	I		No toxic effect.	Aerobic culture.	104
IA-43	Phenyl Methyl Carbinol	F	I		85-95% reduction	Completely mixed activated sludge.	101

(continued)

TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IA-44	n-Propanol	U	P		98.8% reduction based on COD; rate of biodegradation 71 mg COD/g hr.	Activated sludge process.	81

(continued)

TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IB-1	Acetaldehyde	F	I		70-90% reduction.	Treated by aerated lagoon.	100
IB-2	Acetaldehyde	F	I	BOD load of 42 lb day/1000 ft^3	85-95% reduction.	Activated sludge process.	56
IB-3	Acetaldehyde	F,C	I	120-900 ppb	Effluent conc. of 90-1350ppb achieved.	Survey of 2 municipal wastewater treatment plants.	65
IB-4	Acetone	F,C	I	100-600 ppb	Effluent conc. of 50-300 ppb achieved.	See IB-3 for comments.	65
IB-5	Acetone	F	I		70-90% reduction.	Treated by aerated lagoon.	100
IB-6	Acetone	B	S		Completely degraded or lost by stripping.	No identifiable degradation product.	102
IB-7	Acetonitrile	B	U	490 ppm	Oxygen consumption was totally inhibited for 24 hrs.		103
IB-8	Acetonitrile	B	S	500 ppm	Toxic or inhibitory during oxidation periods up to 72 hrs. 1.4% TOD was exerted in 72 hrs.		106
IB-9	Acetylglycine	O	D	500 ppm	Readily oxidized w/9.3% of TOD exerted after 6 hr & 18.5% after 24 hr of oxidation.		106
IB-10	Acrolein	F,C	I	50-150 ppb	Effluent conc. of 20-200 ppb achieved.	Survey of 2 municipal wastewater treatment plants.	65

(continued)

TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IB-11	Acrylic Acid	F	I	BOD load of 42 lb/day/1000 ft^3	85-95% reduction.	Activated sludge process.	56
IB-12	Acrylic Acid	F	I		50-70% reduction.	Treated by aerated lagoon.	100
IB-13	Acrylic Acid	F	I		85-95% reduction.	Completely mixed activated sludge process.	101
IB-14	Acrylonitrile	F	I		70-90% reduction.	Treated by aerated lagoon.	100
IB-15	Acrylonitrile	F	I		95-100% reduction.	Completely mixed activated sludge process.	101
IB-16	Acrylonitrile	F	I	BOD load of 42 lb/day/1000 ft^3	95-100% reduction.	Activated sludge process.	56
IB-17	Acrylonitrile	F	I	140 ppm	100% reduction.	Activated sludge process.	90
IB-18	Adipic Acid	I	D	500 ppm	Readily oxidized w/7.1% of TOD exerted after 24 hr of oxidation.	Oxidation improved greatly after 12 hrs.	107
IB-19	Alanine	B	U	500 ppm	Up to 39% of TOD exerted in 24 hrs.	Oxygen consumption showed no lag period. Material was readily degraded.	103
IB-20	Ammonium Oxalate	U	P		92.5% reduction based on COD; rate of biodegradation 40 mg COD/g hr.	Activated sludge process.	81
IB-21	Butanedinitrile	O	D	500 ppm	Toxic at oxidation periods up to 72 hrs.		106

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IB-22	Butanedinitrile	O	D	500 ppm	Readily, but slowly, oxidized, 3.8% of TOD exerted after 24 hr of oxidation.	Oxygen uptake showed plateau effect after 12 hrs.	107
IB-23	Butanenitrile	O	D	500 ppm	Inhibited oxidation for up to 24 hrs; after 72 hrs, up to 10.5% of TOD was exerted.		106
IB-24	Butanenitrile	O	D		Readily, but slowly oxidized. Most rapid oxidation occurred in first 6 hrs, 1.7% of TOD exerted after 24 hrs.	See IB-23 for comments.	107
IB-25	Butyleneoxide	O	D	500 ppm	9.6% of TOD exerted after 144 hrs of oxidation.	Degraded very slowly.	108
IB-26	Butyric Acid	F	I	BOD load of 42 lb/day/1000 ft^3	85-95% reduction.		56
IB-27	Butyric Acid	O	D	500 ppm	Up to 43% of TOD exerted after 72 hrs of oxidation.		106
IB-28	Butyric Acid	F	I		50-70% reduction.	Treated by aerated lagoon.	100
IB-29	Butyric Acid	O	D		Rapidly oxidized for first 6 hrs; after 24 hrs of oxidation up to 27.9% of TOD was exerted.		107
IB-30	Calcium Gluconate	L	U	250 ppm	13.6% of TOD exerted in 24 hrs.		103
IB-31	Caprolactam	U	P		94.3% reduction based on COD; rate of biodegradation 16 mg COD/g hr.	Activated sludge process	81

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study Study Type[c]	Waste Type[d]	Influent Char.	Results of Study	Comments	Ref.
IB-32	Citric Acid	L	U	550 ppm	35 mg of O_2 used in 24 hrs.	Biodegradable, depressed O_2 consumption.	103
IB-33	Crotonaldehyde	F	I	BOD load of 42 lb/day/1000 ft^3	95-100% reduction.		56
IB-34	Crotonaldehyde	F	I		90-100% reduction.	Treated by aerated lagoon.	100
IB-35	Crotonaldehyde	F	I		95-100% reduction.	Completely mixed activated sludge process.	101
IB-36	Cystine	L	U	1000 ppm	Completely inhibited any consumption of O_2.		103
IB-37	L-Cystine	O	D	500 ppm	Slowly oxidized w/4.7% of TOD exerted after 24 hrs of oxidation.		107
IB-38	Cyclohexanolone	U	P		92.4% reduction based on COD; rate of biodegradation 51.5 mg COD/g hr.	Activated sludge process.	81
IB-39	Cyclohexanone	U	P		96% reduction based on COD; rate of biodegradation 30 mg COD/g hr.	Activated sludge process.	81
IB-40	Cyclopentanone	U	P		95.4% reduction based on COD; rate of biodegradation 57 mg COD/g hr.	Activated sludge process.	81
IB-41	Diethylene Glycol	U	P		95% reduction based on COD; rate of biodegradation 13.7 mg COD/g hr.		81
IB-42	2,3-Dithiabutane	F,C	I	10-120ppb	Not detectable in effluent.	See IB-3 for comments.	65

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IB-43	Dulcitol	O	U	1700 ppm	Slightly inhibitory		109
IB-44	Erucic Acid	O	D	500 ppm	11% of TOD exerted after 24 hrs of oxidation.		107
IB-45	Ethyl Acetate	F	I		90-100% reduction.	Treated by aerobic lagoon.	100
IB-46	Ethyl Acetate	F	I		95-100% reduction.	Completely mixed activated sludge process.	101
IB-47	Ethyl Acetate	F	I	BOD load of 42 lb/day/1000 ft^3	95-100% reduction.	Activated sludge process.	56
IB-48	Ethyl Acrylate	F	I	BOD load of 42 lb/day/1000 ft^3	95-100% reduction.	Activated sludge process	56
IB-49	Ethyl Acrylate	F	I		90-100% reduction.	Treated by aerobic lagoon	100
IB-50	Ethyl Acrylate	F	I		95-100% reduction.	Completely mixed activated sludge process.	101
IB-51	Ethylene Glycol	U	P		96.8% reduction based on COD; rate of biodegradation 41.7 mg COD/g hr.	Activated sludge process.	81
IB-52	2-Ethylhexylacrylate	F	I	BOD load of 42 lb/day/1000 ft^3	95-100% reduction.	Activated sludge process.	56
IB-53	2-Ethylhexylacrylate	F	I		90-100% reduction	Treated by aerobic lagoon.	100

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IB-54	2-Ethylhexylacrylate	F	I		95-100% reduction.	Completely mixed activated sludge process.	101
IB-55	Formaldehyde	L	U	720 ppm	Chemical inhibited O_2 consumption.		103
IB-56	Formaldehyde	O	D	3000 ppm	<99% reduction after 24 hrs of aeration.	pH held at 7.2.	104
IB-57	Formamide	O	D	500 ppm	Slowly oxidized for first 12 hrs; 11.8% of TOD exerted after 24 hrs of oxidation.		107
IB-58	Formic Acid	L		720 ppm	70% of TOD exerted after 24 hrs of oxidation.	No lag period during oxidation.	107
IB-59	Glutamic Acid	L			31% of TOD exerted after 24 hrs of oxidation.		103
IB-60	Glycerine	L		720 ppm	248 mg of O_2 used in 24 hrs.		103
IB-61	Glycine	L		720 ppm	58% of TOD exerted after 24 hrs.		103
IB-62	Heptane	F	I	BOD load of 42 lb/day/1000 ft^3	95-100% reduction.	Activated sludge process.	56
IB-63	Heptane	O	D	500 ppm	38.7% of TOD exerted after 72 hrs.		106
IB-64	Heptane	F	I		90-100% reduction.	Treated by aerated lagoon.	100
IB-65	Heptane	F	I		95-100% reduction.	Completely mixed activated sludge process.	101
IB-66	Hydracrylonitrile	F	I		0-10% reduction.	Treated by aerated lagoon.	100

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IB-67	Isophorone	F,C	D		93% reduction.	21 day maximum retention time in a series of lagoons.	81
IB-68	Lactic Acid	L		720 ppm	78% of TOD exerted after 24 hrs.		7
IB-69	Lauric Acid	0	D	500 ppm	6.1% of TOD exerted after 24 hrs.		107
IB-70	L-Malic Acid	0	D	500 ppm	44.8% of TOD exerted after 24 hrs.		107
IB-71	DL-Malic Acid	0	D	500 ppm	20.8% of TOD exerted after 24 hrs.	A 10-16 hr lag period was indicated.	107
IB-72	Malonic Acid	0	D	500 ppm	Chemical inhibited O_2 uptake.		107
IB-73	Nitrilotriacetate	L	S	20 to 500 ppm	>90% reduction after acclimation.		111
IB-74	Oleic Acid	0			O_2 uptake inhibited.		109
IB-75	Oxalic Acid	L		250 ppm	O_2 uptake inhibited.		103
IB-76	Pentane	O	D	500 ppm	O_2 uptake inhibited.		106
IB-77	Pentanedinitrile	0	D	500 ppm	Toxic at oxidation periods of up to 72 hrs.		106
IB-78	Pentanedinitrile	0	D	500 ppm	Slowly oxidized with 2.9% of TOD exerted after 24 hrs of oxidation.		106
IB-79	Pentanenitrile	0	D	500 ppm	Toxic to 2 sludges at oxidation periods up to 24 hrs.		106
IB-80	Propanedinitrile	0	D	500 ppm	Toxic for oxidation periods up to 72 hrs.		106

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IB-81	Propanenitrile	0	D	500 ppm	Toxic for oxidation periods up to 72 hrs.		106
IB-82	β-Propiolactone	0	D	500 ppm	O_2 uptake inhibited.		108
IB-83	Sodium Alkyl Sulfonate	0			22% of TOD exerted after 5 days.		112
IB-84	Sodium Lauryl Sulfate	0			65% of TOD exerted after 5 days.		112
IB-85	Sodium N-Oleyl-N-Methyl Taurate	0			47-52% of TOD exerted in 5 days.		112
IB-86	Sodium α Sulfo Methyl Myristate	0			33% of TOD exerted after 5 days.		112
IB-87	Tannic Acid	0			O_2 uptake inhibited.		109
IB-88	Thioglycollic Acid	L			O_2 uptake inhibited within 24 hrs.		103
IB-89	Thiouracil	0	D	500 ppm	Chemical was oxidized but very slowly. 12.8% of TOD exerted after 144 hrs of oxidation.		108
IB-90	Thiourea	0	D	500 ppm	O_2 uptake was inhibited by chemical for up to 144 hrs of oxidation.		103
IB-91	Triethylene Glycol	U	P		97.7% reduction based on COD; rate of biodegradation was 27 mg COD/g hr.	Activated sludge process	81
IB-92	Urea	L		1200 ppm	O_2 uptake inhibited.		103

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IB-93	Urethane	0	D		O_2 uptake inhibited.		108

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IC-1	Acetanilide	U	P		94.5% reduction based on COD; rate of biodegradation 19 mg COD/g hr.	Activated sludge process.	81
IC-2	p-Aminoacetanilide	U	P		93% reduction based on COD; rate of biodegradation 11.3 mg COD/g hr.	Activated sludge process.	81
IC-3	m-Aminobenzoic Acid	U	P		97.5% reduction based on COD; rate of biodegradation 27.1 mg COD/g hr.	Activated sludge process.	81
IC-4	o-Aminobenzoic Acid	U	P		97.5% reduction based on COD; rate of biodegradation 7.0 mg COD/g hr.	Activated sludge process.	81
IC-5	p-Aminobenzoic Acid	U	P		96.2% reduction based on COD; rate of biodegradation 12.5 mg COD/g hr.	Activated sludge process.	81
IC-6	m-Aminotoluene	U	P		97.7% reduction based on COD; rate of biodegradation 30 mg COD/g hr.	Activated sludge process.	81
IC-7	o-Aminotoluene	U	P		97.7% reduction based on COD; rate of biodegradation 15.1 mg COD/g hr.	Activated sludge process.	81
IC-8	p-Aminotoluene	U	P		97.7% reduction based on COD; rate of biodegradation 20 mg COD/g hr.	Activated sludge process.	81
IC-9	Aniline	U	P		94.5% reduction based on COD; rate of biodegradation 19 mg COD/g hr.	Activated sludge	81
IC-10	Aniline	U	I	500 ppm 30°C	100% reduction in 15 hrs.	Biodegradation by mutant pseudomonas.	92

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IC-11	Aniline	0	0	500 ppm	O_2 uptake inhibited for up to 72 hrs.		108
IC-12	Benzamide	0	0	500 ppm	O_2 uptake inhibited for first 6 hrs. 63% of TOD exerted after 144 hrs of oxidation.		108
IC-13	Benzidine	0	D	500 ppm	O_2 uptake inhibited.		108
IC-14	Benzidine	F,C	D	1.6 ppb	0% reduction.	Activated sludge process.	81
IC-15	Benzylamine	0	D	500 ppm	O_2 uptake inhibited.		108
IC-16	Butanamide	0	D	500 ppm	Slowly oxidized w/6.4% of TOD exerted after 24 hrs of oxidation.		107
IC-17	m-Chloroaniline	U	P		97.2% reduction based on COD; rate of biodegradation 6.2 mg COD/g hr.	Activated sludge process.	81
IC-18	o-Chloroaniline	U	P		97.2% reduction based on COD; rate of biodegradation 16.7 mg COD/g hr.	Activated sludge process.	81
IC-19	p-Chloroaniline	U	P		96.5% reduction based on COD; rate of biodegradation 5.7 mg COD/g hr.	Activated sludge process.	81
IC-20	Diethanolamine	U	P		97% reduction based on COD; rate of biodegradation 19.5 mg COD/g hr.	Activated sludge process.	81
IC-21	2,3-Dimethylaniline	U	P		96.5% reduction based on COD rate of biodegradation 12.7 mg COD/g hr.	Activated sludge process.	81

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IC-22	2,5-Dimethyl-aniline	U	P		96.5% reduction based on COD; rate of biodegradation 3.6 mg COD/g hr.	Activated sludge process.	81
IC-23	3,4-Dimethyl-aniline	U	P		76% reduction based on COD; rate of biodegradation 30 mg COD/g hr.	Activated sludge process.	81
IC-24	Ethylene-diamine	U	P		97.5% reduction based on COD; rate of biodegradation 9.8 mg COD/g hr.	Activated sludge process.	81
IC-25	2-Fluorenamine	O	D	500 ppm	O_2 uptake showed inhibitory effect but was slowly biologically oxidized.		108
IC-26	o-Nitroaniline	U	I	18.5 ppm	≤99.9% reduction.	Powder activated carbon & activated sludge treatment.	58
IC-27	p-Nitroaniline	U	I	6.7 ppm	≤99.9% reduction.	See IC-26 for comments.	58
IC-28	p-(Phenylazo) aniline	O	D	500 ppm	O_2 uptake inhibited after 72 hrs of oxidation.		108
IC-29	Pentanamide	O	D	500 ppm	Slowly oxidized w/13.6% of TOD exerted after 24 hrs of oxidation.		107
IC-30	Phenylene-diamine	O	D	500 ppm	Toxic during 24 hrs of aeration		113
IC-31	m-Phenylene-diamine	U	P		60% reduction based on COD.	Activated sludge process.	81
IC-32	o-Phenylene-diamine	U	P		33% reduction based on COD.	Activated sludge process.	81
IC-33	p-Phenylene diamine	U	P		80% reduction based on COD.	Activated sludge process.	81

(continued)

TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IC-34	Thioacetamide	L	U	100 ppm	O_2 uptake inhibited.		103
IC-35	2,4,6-Trichloroaniline	U	I	500 ppm	100% reduction in 30 hrs.	See IC-10 for comments.	92
IC-36	2,4,6-Trichloroaniline	O	S	10 ppm	O_2 uptake not inhibited.		113

(continued)

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
ID-1	sec-Amyl-benzene	0	D	500 ppm	Toxic for 24 hrs of aeration.		113
ID-2	tert-Amyl-benzene	0	D	500 ppm	Toxic for 24 hrs of aeration.		113
ID-3	Benzaldehyde	0			O_2 uptake inhibited.		109
ID-4	Benzaldehyde	U	P		99% reduction based on COD; rate of biodegradation 119 mg COD/g hr.	Activated sludge process.	81
ID-5	Benzaldehyde	0	D	500 ppm	61.3% of TOD exerted after 144 hrs of oxidation.		108
ID-6	Benzene	F	I		90-100% reduction.	Treated by aerated lagoon.	100
ID-7	Benzene	F	I		95-100% reduction.	Completely mixed activated sludge process.	101
ID-8	Benzene	0	D	125 ppm	1.44-1.45g of oxygen utilized per gram of substrate added after 72 hrs of oxidation.		114
ID-9	Benzene	0	D	50-500 ppm	O_2 uptake of 34 ppm O_2/hr for 50 ppm chemical & 37 ppm O_2/hr for 500 ppm chemical.		114
ID-10	Benzene	F	I		95-100% reduction.	Activated sludge process.	56
ID-11	Benzene Sulfonate	0	D	500 ppm	Slowly oxidized for first 6 hrs; 62% of TOD exerted after 144 hrs.		108
ID-12	Benzenethiol	0	D	500 ppm	O_2 uptake inhibited for up to 144 hrs of oxidation.		108

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
ID-13	Benzoic Acid	U	P		99% reduction based on COD; rate of biodegradation 88.5 mg COD/g hr.		81
ID-14	Benzoic Acid	F	I	BOD load of 42 lb/day/1000 ft^3	95-100% reduction	Activated sludge process.	56
ID-15	Benzonitrile	O	D	500 ppm	O_2 uptake inhibited for up to 72 hrs of oxidation.		106
ID-16	3,4-Benzpyrene	O	D	500 ppm	O_2 uptake inhibited for up to 144 hrs of oxidation.		106
ID-17	sec-Butylbenzene	O	D	500 ppm	Toxic for 24 hrs of aeration.		113
ID-18	tert-Butylbenzene	O	D	500 ppm	Toxic for 24 hrs of aeration.		113
ID-19	Chloranil	O	S	10 ppm	O_2 uptake inhibited.		102
ID-20	Chlorobenzene	L	P	200 ppm	100% reduction in 14 hrs.	Biodegradation by mutant pseudomonas species.	66
ID-21	1,2,4,5-Dibenzpyrene	O	D	500 ppm	O_2 uptake inhibited for up to 144 hrs of oxidation.		108
ID-22	m-Dichlorobenzene	L	P	200 ppm	100% reduction in 28 hrs.	See ID-20 for comments.	66
ID-23	m-Dichlorobenzene	U	I	200 ppm	100% reduction in 30 hrs.	See ID-20 for comments.	92
ID-24	o-Dichlorobenzene	L	P	200 ppm	100% reduction in 20 hrs.	See ID-20 for comments.	66
ID-25	p-Dichlorobenzene	L	P	200 ppm	100% reduction in 25 hrs.	See ID-20 for comments.	66

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
ID-26	2,4-Dichlorophenoxyacetic Acid	L	D	174 ppm	No reduction until after 5 days.	Subjected to continuous aeration.	115
ID-27	2,6-Dichlorophenoxyacetic Acid	L	D	178 ppm	No reduction until after 3 days.	See ID-26 for comments.	115
ID-28	2,4-Dichlorophenoxypropionic Acid	L	D	186 ppm	No reduction after 7 days.	See ID-26 for comments.	115
ID-29	7,9-Dimethylbenzacridine	O	D	500 ppm	O_2 uptake inhibited after 144 hrs of oxidation.		108
ID-30	7,10-Dimethylbenzacridine	O	D	500 ppm	O_2 uptake inhibited after after 144 hrs of oxidation.		108
ID-31	3,5-Dinitrobenzoic Acid	U	P		50% reduction based on COD.	Activated sludge process.	81
ID-32	2,4-Dinitrotoluene	F,C	D	390 ppb	Not detectable in effluent.	Activated sludge process.	81
ID-33	2,4-Dinitrotoluene	R	U	146-188 ppm	90% reduction.	Activated sludge process.	90
ID-34	Ethylbenzene	F	I	BOD load of 42 lb/day/1000 ft^3	95-100% reduction	Activated sludge process.	56
ID-35	Ethylbenzene	U	S	192 ppb	100% reduction.		21
ID-36	Ethylbenzene	F	I		90-100% reduction.	Treated by aerated lagoon.	100
ID-37	Ethylbenzene	L	I		95-100% reduction	Completely mixed activated sludge.	101

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study: Study Type[c]	Waste Type[d]	Influent Char.	Results of Study	Comments	Ref.
ID-38	Ethylbenzene	O	D	105 ppm	After 72 hrs of oxidation 1.7g of O_2 was used per g chemical added.		114
ID-39	Hexachlorobenzene	L	P	200 ppm	0% reduction in 120 hrs.	See ID-20 for comments.	66
ID-40	Hexachlorobenzene	U	I	200 ppm	0% reduction in 120 hrs.	See ID-20 for comments.	92
ID-41	4-Hydroxybenzenecarbonitrile	O	D	500 ppm	Toxic after 72 hrs of oxidation.		106
ID-42	2-Methylbenzenecarbonitrile	O	D	500 ppm	Toxic after 72 hrs of oxidation.		106
ID-43	3-Methylbenzenecarbonitrile	O	D	500 ppm	Toxic after 72 hrs of oxidation.		106
ID-44	4-Methylbenzenecarbonitrile	O	D	500 ppm	Toxic after 72 hrs of oxidation.		106
ID-45	Methylethylpyridine	F	I		10-30% reduction.	Treated by aerated lagoon.	100
ID-46	m-Nitrobenzaldehyde	U	P		94% reduction based on COD; rate of biodegradation 10 mg COD/g hr.	Activated sludge process.	81
ID-47	o-Nitrobenzaldehyde, p-Nitrobenzaldehyde	U	P		97% reduction based on COD; rate of biodegradation 13.8 mg COD/g hr.	Activated sludge	81
ID-48	Nitrobenzene	U	P		98% reduction based on COD; rate of biodegradation 14 mg COD/g hr.	Activated sludge process.	81

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study Study Type[c]	Waste Type[d]	Influent Char.	Results of Study	Comments	Ref.
ID-49	Nitrobenzene	U	S	175 ppb	100% reduction.		21
ID-50	Nitrobenzene	U	I	530 ppb	≤ 96.0% reduction.	Powder activated carbon & activated sludge treatment.	58
ID-51	Nitrobenzene	F,C	D	58 ppb	>0.1 ppb effluent conc.	21 day maximum retention time in a series of lagoons.	81
ID-52	Nitrobenzene	O	D	500 ppm	O_2 uptake inhibited for up to 144 hrs of oxidation.		108
ID-53	m-Nitrobenzoic Acid	U	P		93.4% reduction based on COD; rate of biodegradation 7 mg COD/g hr.	Activated sludge process.	81
ID-54	o-Nitrobenzoic Acid	U	P		93.4% reduction based on COD; rate of biodegradation 20 mg COD/g hr.	Activated sludge process.	81
ID-55	p-Nitrobenzoic Acid	U	P		92% reduction based on COD; rate of biodegradation 19.7 mg COD/g hr.	Activated sludge process.	81
ID-56	m-Nitrotoluene	U	P		98.5% reduction based on COD; rate of biodegradation 21 mg COD/g hr.	Activated sludge process.	81
ID-57	o-Nitrotoluene p-Nitrotoluene	U	P		98% reduction based on COD; rate of biodegradation 32.5 mg COD/g hr.	Activated sludge process.	81
ID-58	Nitrofluorine	O	D	500 ppm	Slowly oxidized w/13.7% of TOD exerted after 144 hrs.		108
ID-59	Paraldehyde	F	I		30-50% reduction	Treated by aerated lagoon.	100

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
ID-60	Pentamethylbenzene	0	D	500 ppm	O_2 uptake inhibited during first 24 hrs of aeration.		113
ID-61	n-Propylbenzene	0	D	37.5 ppm	After 72 hrs of oxidation 0.67g of O_2 were utilized per g of substrate added.		114
ID-62	Sodium Alkylbenzene Sulfonate	0			26% of TOD exerted after 5 days.		112
ID-63	Styrene	F	I		70-90% reduction.	Treated by aerated lagoon.	100
ID-64	Styrene	F	I		95-100% reduction.	Completely mixed activated sludge process.	101
ID-65	1,2,3,4-Tetrachlorobenzene	L	P	200 ppm	74% reduction in 120 hrs.	See ID-20 for comments.	66
ID-66	1,2,3,5-Tetrachlorobenzene	L	P	200 ppm	80% reduction in 120 hrs.	See ID-20 for comments.	66
ID-67	1,2,4,5-Tetrachlorobenzene	U	I	200 ppm	80% reduction in 120 hrs.	See ID-20 for comments.	66
ID-68	1,2,4,5-Tetrachlorobenzene	0	0	500 ppm	No O_2 consumed during first 3 hrs; very slight uptake thereafter for first 24 hrs of aeration.		113
ID-69	Toluene	F	I		70-90% reduction.	Treated by aerated lagoon.	100
ID-70	Toluene	F	I		95-100% reduction.	Completely mixed activated sludge process.	101
ID-71	Toluene	0	D	500 ppm	O_2 uptake inhibited or very slightly oxidized for first 24 hrs of oxidation.		108

(continued)

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
ID-72	Toluene	O	D	100 ppm	0.53-0.65g of O_2 used per g of substrate added after 72 hrs of oxidation.		114
ID-73	Toluene	O	D	500 ppm	48.3% of TOD exerted after 72 hrs of oxidation.		106
ID-74	Toluene	F,C	I	8-150 ppb	1.0-10.0 ppb effluent conc.	Survey of 2 municipal wastewater treatment plants.	65
ID-75	Toluene	F	I	BOD load of 42 lb day/1000 ft^3	95-100% reduction.	Activated sludge process.	56
ID-76	m-Toluidine	U	I	500 ppm	100% reduction in 10 hrs.	See ID-20 for comments.	92
ID-77	1,2,3-Trichlorobenzene	L	P	200 ppm	100% reduction in 43 hrs.	See ID-20 for comments.	66
ID-78	1,2,4-Trichlorobenzene	L	P	200 ppm	100% reduction in 46 hrs.	See ID-20 for comments.	66
ID-79	1,3,5-Trichlorobenzene	U	I	200 ppm	100% reduction in 50 hrs.	See ID-20 for comments.	92
ID-80	1,3,5-Trichlorobenzene	L	P	200 ppm	100% reduction in 50 hrs.	See ID-20 for comments.	66
ID-81	2,4,5-Trichlorophenoxypropionic Acid	L	O	107.5 ppm	99% reduction in 16.5 days.		115
ID-82	2,4,6-Trichlorophenoxyacetic Acid	L	D	53 ppm	50% reduction in 14 days.	Subjected to continuous aeration.	115
ID-83	2,6,6-Trinitrotoluene	L	I	100 ppm	50-84% reduction in 3-14 hrs.		116

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
ID-84	m-xylene o-xylene p-xylene	O	D	500 ppm	O_2 uptake inhibited after 24 hrs of oxidation.		113
ID-85	Xylene	F,C	I	20-200ppb	1.0-15.0 ppb effluent conc.	See ID-74 for comments.	65

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Ethers (E)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IE-1	Isopropyl Ether	F	I	BOD load of 42 lb/day/1000 ft^3	85-95% reduction.	Activated sludge process.	56
IE-2	Isopropyl Ether	F	I		70-90% reduction.	Treated by aerated lagoon.	100
IE-3	Isopropyl Ether	F	I		85-95% reduction.	Completely mixed activated sludge process.	101

(continued)

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IF-1	Bromoform	F,C	I	0.4-1.9 ppb	100% reduction.	Survey of 2 municipal wastewater treatment plants.	65
IF-2	Carbon Tetrachloride	U	S	177 ppb	100% reduction.		21
IF-3	Chloroform	F,C	I	13 ppb	100% reduction.	See IF-1 for comments.	65
IF-4	1,2-Dichloro-ethane	F,C	I	0.4-260 ppb	1.4 ppb effluent conc.	See IF-1 for comments.	65
IF-5	Methylene Chloride	F,C	I	10-430ppb	2.0-50 ppb effluent conc.	See IF-1 for comments.	65
IF-6	1,1,1-Trichloroethane	F,C	I	8.0-790 ppb	1.0-20.0 ppb effluent conc.	See IF-1 for comments.	65
IF-7	1,1,2-Trichloroethane	U	I	1305 ppb	$\leq$ 99.7% reduction.	Powder activated carbon & activated sludge treatment.	58
IF-8	Trichloro-ethylene	F,C	I	78 ppb	100% reduction.	See IF-1 for comments.	65
IF-9	Trichloro-ethylene	F,C	I	214 ppb	99% reduction		21
IF-10	Vinyl Chloride	F,C	I	8 ppb	100% reduction	See IF-1 for comments.	65

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IG-1	Barium	O	U	1-100,000 ppm	O_2 uptake inhibited at conc. greater than 100 ppm.		109
IG-2	Cadmium	R	U	6 ppb	1.0 ppb effluent conc.	Activated sludge process.	90
IG-3	Cadmium	F,C	I	27 ppb	16 ppb effluent conc.	Survey of 2 municipal wastewater treatment plants.	65
IG-4	Cadmium	O	U	1-100,000 ppm	Conc. of 1-10 ppm inhibited O_2 uptake.		109
IG-5	Chromium	F	D	ranged from 0.8-3.6ppm	22-78% reductions achieved.	Survey of municipal wastewater treatment plants.	122
IG-6	Chromium (Cr^{+3})	C,P	D	15 ppm	0.2 ppb effluent conc.		123
IG-7	Chromium (Cr^{+6})	O	U	1-100,000 ppm	O_2 uptake inhibited at conc. greater than 100 ppm.		109
IG-8	Cobalt	L	S	0.08-0.5 ppm	Inhibited biological growth.	Study of Nitrosomas bacteria.	124
IG-9	Copper	R	U	10 ppm	75% reduction.	Activated sludge process.	118
IG-10	Copper	F	D	ranged from 0.2-1.5ppm	7-77% reductions achieved.	See IG-5 for comments.	122
IG-11	Copper	L	S	5-30 ppb 50-560ppb	Stimulated biological growth Inhibited biological growth.	See IG-8 for comments.	124
IG-12	Copper	C,P	D	10 ppm	75% reduction.	Activated sludge process.	125
IG-13	Iron (Fe^{+2})	O	U	10-1000 ppm	O_2 uptake inhibited at conc. greater than 100 ppm.		109

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IG-14	Iron (Fe^{+3})	O	U	0.01-100,000 ppm	O_2 uptake inhibited at conc. greater than 100 ppm.		109
IG-15	Iron	C,F	D	7.17 ppm total iron	83% reduction.		126
				0.6 ppm soluble iron	62% reduction.		
IG-16	Lead	O		10-100ppm	O_2 uptake inhibited		109
IG-17	Lead	L	S	5-50 ppb	No stimulation or inhibition of biological growth.	See IG-8 for comments.	124
IG-18	Manganese	L	S	12.5-50 ppm	Stimulated biological growth	See IG-8 for comments.	124
				50-100ppm	Inhibited biological growth.		
IG-19	Manganese	L	S	10 ppm	O_2 uptake inhibited.		109
IG-20	Mercury	O	S	0-200 ppm	O_2 uptake inhibited.		127
IG-21	Mercury	L	S	5-10 ppm	51-58% reduction.		132
IG-22	Nickel	R	U	10 ppm	28% reduction.	Activated sludge process.	118
IG-23	Nickel	F	D	ranged from 0.03-2.0 ppm	0-33% reduction achieved.	See IG-5 for comments.	122
IG-24	Nickel	C,P	D	1-10 ppm	28-42% reduction.	Activated sludge process.	128

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IG-25	Nickel	C,F	D	270 ppb	30% reduction.	Activated sludge process.	129
IG-26	Nickel	P	D	10 ppm	28% reduction.	Activated sludge process.	125
IG-27	Strontium	L	S	5-50 ppb	No stimulation or inhibition of biological growth.	See IG-8 for comments.	124
IG-28	Zinc	R	U	10 ppm	89% reduction.	Activated sludge process.	118
IG-29	Zinc	F	D	ranged from 0.3-2.2ppm	20-91% reduction achieved.	See IG-5 for comments.	122
IG-30	Zinc	C,P	D	2.5 ppm	13% reduction in primary treatment.		128
				10 ppm	14% reduction in primary treatment.		
IG-31	Zinc	L	S	0.08-0.5 ppm	Biological growth inhibited.	See IG-8 for comments.	124
IG-32	Zinc	C,F	D	0.91 ppm	60% reduction.	Activated sludge process.	131
IG-33	Zinc	L	S	1 ppm	O_2 uptake inhibited.		109
IG-34	Zinc	R	U	3.57 ppm	57% reduction.	Activated sludge process.	90

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IJ-1	Aldrin	O	U		Not significantly degraded.		121
IJ-2	Aminotriazole	O	U		Not significantly degraded.		121
IJ-3	Chlordane	O	U		Slightly degraded.		121
IJ-4	2,4-D-Isoctyl-ester	O	U		Biodegradable.		121
IJ-5	DDT	O	U		Not significantly degraded.		121
IJ-6	DDVP	L	U	37.5°C, 8.0 pH	462 min half-life.	Biodegradation by mutant pseudomonas species.	92
IJ-7	Diazinon	L	U	20°C, 10.4 pH	144 hr half-life.	See IJ-6 for comments.	92
IJ-8	Diazinon	O	U		Not significantly degraded.		121
IJ-9	Dieldrin	O	U		Not significantly degraded.		121
IJ-10	Endrin	O	U		Not significantly degraded.		121
IJ-11	Ferbam	O	U		Biodegradable.		121
IJ-12	Heptachlor	O	U	500 ppm	Slightly degraded.		121
IJ-13	Herbicide Orange	F	I	1380 ppm	77% reduction.	Pure O_2 & biological seeding provided.	81
IJ-14	Lindane	O	U		Not significantly degraded.		121

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IJ-15	Malathion	O	U		Not significantly degraded.		121
IJ-16	Malathion	L	U	25°C, 10.03 pH	28 min half-life.	See IJ-6 for comments.	92
IJ-17	Maneb	O	U		Biodegradable		121
IJ-18	Methyl Parathion	L	U	15°C	7.5 min half-life.	See IJ-6 for comments.	92
IJ-19	Methyl Parathion	O	U		Not significantly degraded.		121
IJ-20	Parathion	L	U	15°C	32 min half-life.	See IJ-6 for comments.	92
IJ-21	Parathion	O	U		Not significantly degraded.		121
IJ-22	Pentachlorophenol	O	U	75-150ppm	Not significantly degraded.		121
IJ-23	Propoxur	O	U	20°C, 10.0 pH	40 min half-life.	See IJ-6 for comments.	92
IJ-24	Tetraethyl Pyrophosphate	O	U		Not significantly degraded.		121
IJ-25	Thanite	O	U		Biodegradable		121
IJ-26	2,4,5-Trichlorophenoxyacetic Acid	O	U	150 ppm	Slightly degraded.		121
IJ-27	2,4,5-Trichlorophenoxyacetic Acid	O			99% reduction in 7.5 days.	Subjected to continuous aeration.	115

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IJ-28	Ziram	O	U		Slightly degraded.		121
IJ-29	Zireb	O	U		Slightly degraded.		121

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IK-1	4-Chloro-3-Methylphenol	O	S	10 ppm 50 ppm 100 ppm	O_2 uptake mildly inhibited. O_2 uptake strongly inhibited. Toxic		102
IK-2	4-Chloro-3-Methylphenol	R	U	25 ppm	Biodegradable in 5 days.		90
IK-3	2-Chloro-4-Nitrophenol	U	P		71.5% reduction based on COD; rate of biodegradation 5.3 mg COD/g hr.	Activated sludge process.	81
IK-4	2-Chlorophenol	R	U	150-200 ppm	90-95% reduction.	Activated sludge process.	90
IK-5	m-Chlorophenol	L	P	200 ppm	100% reduction in 28 hrs.	Biodegradation by mutant pseudomonas species.	66
IK-6	o-Chlorophenol	L	P	200 ppm	100% reduction in 26 hrs.	See IK-5 for comments.	66
IK-7	o-Chlorophenol	U	P		95.6% reduction based on COD; rate of biodegradation 25 mg COD/g hr.	Activated sludge process.	81
IK-8	p-Chlorophenol	U	P		96% reduction based on COD; rate of biodegradation 11 mg COD/g hr.	Activated sludge process.	81
IK-9	p-Chlorophenol	L	P	200 ppm	100% reduction in 33 hrs.	See IK-5 for comments.	66
IK-10	m-Cresol	U	P		96% reduction based on COD; rate of biodegradation 55 mg COD/g hr.	Activated sludge process.	81
IK-11	o-Cresol	U	P		95% reduction based on COD; rate of biodegradation 54 mg COD/g hr.	Activated sludge process.	81

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IK-12	p-Cresol	U	P		95.5% reduction based on COD; rate of biodegradation 55 mg COD/g hr.	Activated sludge process.	81
IK-13	2,4-Diamino-phenol	U	P		83% reduction based on COD; rate of biodegradation 12 mg COD/g hr.	Activated sludge process.	81
IK-14	2,4-Dichloro-phenol	U	P		98% reduction based on COD; rate of biodegradation 10.5 mg COD/g hr.	Activated sludge process.	81
IK-15	2,4-Dichloro-phenol	R	U	60 ppm	Biodegradable in 5 days.		90
IK-16	2,4-Dichloro-phenol	U	I	200 ppm	100% reduction in 35 hrs.	See IK-5 for comments.	90
IK-17	2,4-Dichloro-phenol	L	P	200 ppm	100% reduction in 33 hrs.	See IK-5 for comments.	90
IK-18	2,4-Dichloro-phenol	L	I	64 ppm	98% reduction in 5 days	Subjected to continuous aeration.	115
IK-19	2,5-Dichloro-phenol	L	P	200 ppm	100% reduction in 38 hrs.	See IK-5 for comments.	66
IK-20	2,6-Dichloro-phenol	L	I	64 ppm	99% reduction in 5 days.	See IK-18 for comments.	115
IK-21	2,3-Dimethyl-phenol	U	P		95.5% reduction based on COD; rate of biodegradation 35 mg COD/g hr.	Activated sludge process.	81
IK-22	2,4-Dimethyl-phenol	U	P		94.5% reduction based on COD; rate of biodegradation 28.2mg COD/g hr.	Activated sludge process.	81
IK-23	2,5-Dimethyl-phenol	U	P		94.5% reduction based on COD; rate of biodegradation 10.6 mg COD/g hr.	Activated sludge process.	81

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TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study: Study Type[c]	Description of Study: Waste Type[d]	Description of Study: Influent Char.	Results of Study	Comments	Ref.
IK-24	2,6-Dimethyl-phenol	U	P		94.3% reduction based on COD; rate of biodegradation 9 mg COD/g hr.	Activated sludge process.	81
IK-25	3,4-Dimethyl-phenol	U	P		97.5% reduction based on COD; rate of biodegradation 13.4 mg COD/g hr.	Activated sludge process.	81
IK-26	3,5-Dimethyl-phenol	U	P		89.3% reduction based on COD; rate of biodegradation 11.1 mg COD/g hr.	Activated sludge process.	81
IK-27	2,4-Dinitro-phenol	O	S	1 ppm	Maximum O_2 uptake was 27.7ppm O_2/hr after 120 hrs of aeration		117
				5 ppm	Maximum O_2 uptake was 21.3ppm O_2/hr after 120 hrs of aeration.		
IK-28	2,4-Dinitro-phenol	U	P		85% reduction based on COD; rate of biodegradation 6 mg COD/g hr.	Activated sludge process.	81
IK-29	m-Nitrophenol p-	U	P		95% reduction based on COD; rate of biodegradation 17.5 mg COD/g hr.	Activated sludge process.	81
IK-30	o-Nitrophenol	U	P		97% reduction based on COD; rate of biodegradation 14 mg COD/g hr.	Activated sludge process.	81
IK-31	o-Nitrophenol	U	I	1275 ppb	$\leq$ 98.1% reduction.	Powder activated carbon & activated sludge treatment.	58
IK-32	p-Nitrophenol	U	I	725 ppb	$\leq$ 99.5% reduction.	See IK- 31 for comments.	58

(continued)

TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IK-33	Pentachlorophenol	L	P	200 ppm	26% reduction in 120 hrs.	See IK-5 for comments.	66
IK-34	Pentachlorophenol	L	P	200 ppm	26% reduction in 120 hrs.	See IK-5 for comments.	92
IK-35	Phenol	R	U	150-200 ppm	90-95% reduction.	Activated sludge process.	90
IK-36	Phenol	U	I	19 ppm	$\leq$ 99.9% reduction.	See IK-31 for comments.	58
IK-37	Phenol	F	I	200 ppm	95% reduction.	Activated sludge process.	118
IK-38	Phenol	F	I	5 ppm	71% reduction.	Acclimated aerobic culture.	119
				18 ppm	62% reduction.		
IK-39	Phenol	O	D	500 ppm	11.6% of TOD exerted after 72 hrs of oxidation.		106
IK-40	Phenol	O	D	500 ppm	O_2 uptake inhibited for first 24 hrs of oxidation. 41.2% TOD exerted in 144 hrs.		108
IK-41	Phenol	B,C	I	120 ppm @ 500 gpm	< 200 ppb effluent conc.	Activated sludge process.	88
IK-42	Phenol	L	P	200 ppm	100% reduction in 8 hrs.	See IK- 5 for comments.	66
IK-43	Phenol	U	I	500 ppm	100% reduction in 10 hrs.	See IK- 5 for comments.	92
IK-44	p-Phenylazophenol	O	D	500 ppm	O_2 uptake inhibited.		108
IK-45	Sodium Pentachlorophenol	L	D	15 ppm	0% reduction.		120
IK-46	2,3,5-Trichlorophenol	U	I	200 ppm	100% reduction in 55 hrs.	See IK- 5 for comments.	92

(continued)

TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IK-47	2,3,5-Trichlorophenol	L	P	200 ppm	100% reduction in 52 hrs.	See IK-5 for comments.	66
IK-48	2,4,5-Trichlorophenol	L	D	18.8 ppm	99% reduction in 6.5 days.	See IK-18 for comments.	115
IK-49	2,4,6-Trichlorophenol	R	U	20 ppm	Biodegradable in 5 days.		90
IK-50	2,4,6-Trichlorophenol	L	P	200 ppm	100% reduction in 50 hrs.	See IK- 5 for comments.	66
IK-51	2,4,6-Trichlorophenol	O	S	1-10 ppm	O_2 uptake showed no inhibitory effect.		102
				50-100ppm	O_2 uptake inhibited.		
IK-52	2,4,6-Trichlorophenol	L	D		99% reduction in 5 days.	See IK- 18 for comments.	115

(continued)

TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Phthalates (L)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IL-1	Bis(2-ethylhexyl) Phthalate	R	U	5 ppm	70-78% reduction.	Activated sludge process.	90
IL-2	Butylbenzyl Phthalate	R	U		Biodegradable.		90
IL-3	Di-N-Butyl Phthalate	R	U		Biodegradable in an environmental system at a level of 200 ppm.		90
IL-4	Diethyl Phthalate	R	U		Biodegradable.		90
IL-5	Di(2-ethylhexyl) Phthalate	F	I		50-70% reduction.	Treated by aerated lagoon.	100
IL-6	Dimethyl Phthalate	R	U		Biodegradable, no inhibition of bacteria at levels of 1000 ppm.		90
IL-7	Dimethyl Phthalate	U	S	215 ppb	100% reduction.		21
IL-8	Di-N-Octyl Phthalate	R	U		Biodegradable in an environmental system at a level of 63 ppm.		90
IL-9	Isophthalic Acid	U	P		95% reduction based on COD; rate of biodegradation 78.4 mg COD/g hr.	Activated sludge process.	81
IL-10	Phthalimide	U	P		96.2% reduction based on COD; rate of biodegradation 20.8 mg COD/g hr.	Activated sludge process.	81
IL-11	Phthalic Acid	U	P		96.8% reduction based on COD; rate of biodegradation 78.4 mg COD/g hr.	Activated sludge process.	81

(continued)

TABLE C-1 (continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Polynuclear Aromatics (M)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IM-1	Anthracene	O	D	500 ppm	Toxic or inhibitory for up to 24 hrs.		108
IM-2	Benzanthracene	O	D	500 ppm	Slowly oxidized; 2.1% of TOD exerted in 144 hrs of oxidation.		108
IM-3	Benzoperylene	R	U		Biodegradable from a conc. of 4×10^{-7} mg/l.		90
IM-4	D-Chloramphenicol	U	P		86.2% reduction based on COD; rate of biodegradation 3.3 mg COD/g hr.	Activated sludge process.	81
IM-5	α,α´-Diethylstilbenediol	O	D		O_2 uptake inhibited.		108
IM-6	9,10-Dimethylanthracene	O	D	500 ppm	O_2 uptake was not inhibited. Up to 19.5% of TOD was exerted after 144 hr of oxidation.		108
IM-7	9,10-Dimethyl-1,2-benzanthracene	O	D	500 ppm	Slowly oxidized; 12.7% of TOD exerted after 144 hr of oxidation.		
IM-8	1,2-Diphenylhydrazine	F,C	D	341 ppb @ 45 MGD	28% reduction.	Activated sludge process.	81
IM-9	7-Methyl-1,2-benzanthracene	O	D	500 ppm	O_2 uptake inhibited at least 24 hrs.		108
IM-10	20-Methylcholanthrene	O	D	500 ppm	Chemical showed both toxic or inhibitory effect & the ability to undergo slow biological oxidation.		108
IM-11	Naphthalene	F	I		70-90% reduction.	Treated by aerated lagoon.	100

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TABLE C-1(continued)

Concentration Process: Biological Treatment (I)
Chemical Classification: Polynuclear Aromatics (M)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IM-12	Naphthalene	F	I		85-95% reduction.	Completely mixed aerated lagoon	101
IM-13	Naphthalene	O	D	500 ppm	O_2 uptake inhibited for 24 hrs.		108
IM-14	Naphthalene	F	I	BOD load of 42 lb/day/1000 ft^3	85-95% reduction.	Activated sludge process.	56

(continued)

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TABLE C-1(continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II D-1	Ethyl Benzene	R	D+P	153 ppb	56% reduction w/alum.	Chemical coagulation was followed by dual media filtration.	21
II D-2	Nitrobenzene	R	D+P	160 ppb	34% reduction w/alum.	See IID-1 for comments.	21

(continued)

TABLE C-1 (continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II F-1	Carbon Tetrachloride	R	D+P	140 ppb	51% reduction w/alum.	Chemical coagulation was followed by dual media filtration.	21
II F-2	Trichloroethylene	R	D+P	103 ppb	40% reduction w/alum.	See IIF-1 for comments.	21

(continued)

TABLE C-1(continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II G-1	Antimony	P	S	600 ppb	62% reduction w/alum; 28% reduction w/lime.	3 coagulants used: 220 ppm of alum @ pH=6.4. 40 ppm of ferric chloride @ pH=6.2; 415 ppm of lime @ pH=11.5; Chemical coagulation was followed by dual media filtration.	39
				500 ppb	65% reduction w/ferric chloride.		
II G-2	Arsenic	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system- 90% reduction; Low lime system- 80% reduction; High lime system- 76% reduction.	3 coagulant systems were used: Iron system used 45 ppm as Fe of $Fe_2(SO_4)_3$ @pH=6.0. Low lime system used 20 ppm as Fe of $Fe_2(SO_4)_3$ & 260 ppm of CaO @ pH=10.0. High lime system used 600 ppm of CaO @ pH=11.5. Chemical coagulation was followed by multimedia filtration.	63
II G-3	Arsenic	F,C	D	2.5 ppb	56% reduction w/lime.	Lime dose of 350-400ppm as calcium oxide @ pH=11.3.	64
				3.3 ppb	24% reduction w/lime.		
II G-4	Arsenic (As^{+5})	R	U	25 ppm	97% reduction by lime softening.		90
				21 ppm	94% reduction by precipitation w/alum.		

(continued)

TABLE C-1 (continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II G-5	Barium	F,C	D	81 ppb	49% reduction w/lime.	See IIG-3 for comments.	64
				81 ppb	36% reduction w/lime.		
II G-6	Barium	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system- 94% reduction; Low lime sytem-99% reduction; High lime system-78% reduction.	See IIG-2 for comments.	63
II G-7	Barium	P	S	500 ppb	79% reduction w/alum.	See IIG-1 for comments.	39
II G-8	Beryllium	R	U	100 ppb	97.8% reduction by lime softening.		90
II G-9	Beryllium	P	S	100 ppb	98.1% reduction w/alum; 94% reduction w/ferric chloride; 99.4% reduction w/lime.	See IIG-1 for comments.	39
II G-10	Bismuth	P	S	600 ppb	95.5% reduction w/ alum. 95.3% reduction w/lime.	See IIG-1 for comments.	39
				500 ppb	94% reduction w/ferric chloride.		
II G-11	Cadmium	P	S	700 ppb	45% reduction by ferric chloride.	See IIG-1 for comments.	39
II G-12	Cadmium	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system- 93% reduction; Low lime system-95% reduction High lime system-98% reduction.	See IIG-2 for comments.	63
II G-13	Cadmium	F,C	D	29 ppb	92% reduction w/lime.	See IIG-3 for comments.	64
				9 ppb	68% reduction w/lime.		

(continued)

TABLE C-1 (continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II G-14	Chromium	L,C	S	5.2 ppm	26.9% reduction w/lime.	Lime dose of 50 ppm added.	16
II G-15	Chromium	F,C	D	154 ppb	37% reduction w/lime.	See IIG-3 for comments.	64
				192 ppb	54% reduction w/lime.		
II G-16	Chromium (Cr^{+3})	P	S	700 ppb	97.6% reduction w/ferric chloride.	See IIG-1 for comments.	39
II G-17	Chromium (Cr^{+3})	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system - 99% reduction; Low lime system - 98% reduction; High lime system - 98% reduction.	See IIG-2 for comments.	63
II G-18	Chromium (Cr^{+6})	P	S	700 ppb	64% reduction w/ferric chloride.	See IIG-1 for comments.	39
II G-19	Chromium (Cr^{+6})	P	D+P	5 ppm @ gpm @ pH=7.0	Iron system - 65% reduction; Low lime system - 40% reduction; High lime system - 22% reduction.	See IIG-2 for comments.	63
II G-20	Cobalt	P	S	500 ppb	18% reduction w/ferric chloride; 91% reduction w/lime.	See IIG-1 for comments.	39
				800 ppb	49% reduction w/alum.		
II G-21	Copper	P	S	700 ppb	67% reduction w/alum.	See IIG-1 for comments.	39
II G-22	Copper	L,C	S	4.6 ppm	97.8% reduction w/lime.	See IIG-14 for comments.	16

(continued)

TABLE C-1(continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II G-23	Copper	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system- 95.6% reduction Low lime system-92.8% reduction; High lime system- 84% reduction.	See IIG- 2 for comments.	63
II G-24	Copper	F,C	D	266 ppb 285 ppb	73% reduction w/lime. 93% reduction w/lime.	See IIG- 3 for comments.	64
II G-25	Copper	R	U	15 ppm	96% reduction.		90
II G-26	Iron	L,C	S	10 ppm	99% reduction w/lime.	See IIG- 14 for comments.	16
II G-27	Iron	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system- 26% reduction; Low lime system-94% reduction	See IIG- 2 for comments.	63
II G-28	Iron	F,C	D	179 ppb 325 ppb	91% reduction w/lime. 88% reduction w/lime.	See IIG- 3 for comments.	64
II G-29	Lead	L,C	S	4.9 ppm	100% reduction w/lime.	See IIG- 14 for comments.	16
II G-30	Lead	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system- 99% reduction; Low lime system-99% reduction High lime system-98% reduction.	See IIG- 2 for comments.	63
II G-31	Lead	F,C	D	40 ppb 19 ppb	43% reduction w/lime. 81% reduction w/lime.	See IIG- 3 for comments.	64

(continued)

TABLE C-1 (continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II G-32	Lead	R	U	330 ppb	94.4% reduction w/lime.	Lime dose of 400 ppm added.	90
II G-33	Lead	P	S	600 ppb	95.5% reduction w/alum.	See IIG-1 for comments.	39
II G-34	Manganese	P	S	700 ppb	30% reduction w/alum.	See IIG-1 for comments.	39
II G-35	Manganese	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system- 18% reduction; Low lime system-93% reduction; High lime system-98% reduction.	See IIG-2 for comments.	63
II G-36	Manganese	F,C	D	35 ppb	87% reduction w/lime.	See IIG-3 for comments.	64
				38 ppb	96% reduction w/lime.		
II G-37	Mercury	P	D+P	0.5 ppm @ 4 gpm @ pH=7.0	High lime system-70% reduction.	See IIG-2 for comments.	63
II G-38	Mercury	F,C	D	9 ppb	71% reduction w/lime.	See IIG-3 for comments.	64
				1.2 ppb	25% reduction w/lime.		
II G-39	Mercury	P	S	500 ppb	70% reduction w/lime.	See IIG-1 for comments.	39
				60 ppb	94% reduction w/alum.		
				50 ppb	98% reduction w/ferric chloride.		
II G-40	Molybdenum	P	S	600 ppb	68% reduction w/ferric chloride; 0% reduction w/alum.	See IIG-1 for comments.	39
				500 ppb	0% reduction w/lime.		

(continued)

TABLE C-1 (continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II G-41	Nickel	P	S	900 ppb	25% reduction w/alum.	See IIG-1 for comments.	39
II G-42	Nickel	L,C	S	4.8 ppm	100% reduction w/lime.	See IIG-14 for comments.	16
II G-43	Nickel	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system- 10% reduction; Low lime system-94% reduction; High lime system-97% reduction.	See IIG-2 for comments.	63
II G-44	Nickel	R	U		52.4% reduction w/lime.	Lime dose of 400 ppm added.	90
II G-45	Selenium	P	S	100 ppb	75% reduction w/ferric chloride.	See IIG-1 for comments.	39
				500 ppb	35% reduction w/lime; 48% reduction w/alum.		
II G-46	Selenium	F,C	D	<2.5 ppb	0% reduction w/lime.	See IIG-3 for comments.	64
				6.5 ppb	0% reduction w/lime.		
II G-47	Selenium	R	U	100 ppm	80% reduction w/ferric sulfate.	Ferric sulfate dose of 100 ppm.	90
II G-48	Silver	P	S	500 ppb	98.2% reduction w/ferric chloride; 97.1% reduction w/lime.	See IIG-1 for comments.	39
				600 ppb	96.9% reduction w/alum.		
II G-49	Silver	F,C	D	5.5 ppb	85% reduction w/lime.	See IIG-3 for comments.	64
				13 ppb	38% reduction w/lime.		

(continued)

TABLE C-1(continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
II G-50	Silver	R	U	500 ppm	96% reduction w/lime.		90
II G-51	Thallium	R	U	500 ppb	54% reduction w/lime.		90
II G-52	Thallium	P	S	600 ppb	30% reduction w/ferric chloride; 31% reduction w/alum.	See IIG-1 for comments.	39
				500 ppb	60% reduction w/lime.		
II G-53	Tin	P	S	500 ppb	98% reduction w/ferric chloride; 92% reduction w/lime.	See IIG-1 for comments.	39
				600 ppb	95.3% reduction w/alum.		
II G-54	Titanium	P	S	500 ppb	98% reduction w/ferric chloride; 95.5% reduction w/lime.	See IIG-1 for comments.	39
				600 ppb	95.8% reduction w/alum.		
II G-55	Vanadium	P	S	500 ppb	97.2% reduction w/ferric chloride; 94% reduction w/ alum; 57% reduction w/lime.	See IIG-1 for comments.	39
II G-56	Zinc	P	S	2.5 ppm	1% reduction w/alum.	See IIG-1 for comments.	39
II G-57	Zinc	P	D+P	5 ppm @ 4 gpm @ pH=7.0	Iron system- 63% reduction; Low lime system-85% reduction; High lime system-76% reduction.	See IIG-2 for comments.	63
II G-58	Zinc	L,C	S	6.4 ppm	100% reduction w/lime.	See IIG-14 for comments.	16

(continued)

TABLE C-1 (continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II G-59	Zinc	F,C	D	300 ppb 380 ppb	90% reduction w/lime. 37% reduction w/lime.	See IIG-3 for comments.	64
II G-60	Zinc	R	U		40.6% reduction by sedimentation.		90
II G-61	Zinc	R	U		91.4% reduction w/lime.	Lime dose of 400 ppm added.	90

(continued)

TABLE C-1(continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II J-1	DDT	L,C	R+P	10 ppb	98% reduction w/alum.	Chemical coagulation was followed by sand filtration.	6
II J-2	Dieldrin	L,C	R+P	10 ppb	55% reduction w/alum.	See IIJ-1 for comments.	6
II J-3	Endrin	L,C	R+P	10 ppb	35% reduction w/alum.	See IIJ-1 for comments.	6
II J-4	Lindane	L,C	R+P	10 ppb	<10% reduction w/alum.	See IIJ-1 for comments.	6
II J-5	Parathion	L,C	R+P	10 ppb	5% reduction w/alum.	See IIJ-1 for comments.	6
II J-6	2,4,5-T ester	L,C	R+P	10 ppb	65% reduction w/alum.	See IIJ-1 for comments.	6

(continued)

TABLE C-1 (continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Phthalates (L)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II L-1	Bis(2-ethylhexyl)Phthalate	R	U	0.5-3.5 ppb @ pH=10.0	80-90% reduction w/$Al_2(SO_4)_3$		90
II L-2	Di-n-Butyl Phthalate	R	U	2.5-4.5 ppb @ pH=10.0	60-70% reduction w/$Al_2(SO_4)_3$		90
II L-3	Dimethyl Phthalate	R	D+P	183 ppb	15% reduction w/alum.	Chemical coagulation was followed by dual media filtration.	21

(continued)

TABLE C-1 (continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Polynuclear Aromatics (M)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II M-1	Acenaphthene	R	U	0.1-0.9 ppm	Precipitation w/alum.		90
II M-2	Acenaphthylene	R	U	0.1-0.9 ppm	Precipitation w/alum.		90
II M-3	Benzanthracene	R	U		Separable by gravity or sand filtration.		90
II M-4	11,12-Benzo-fluoranthene	R	U		Separable by gravity or sand filtration.		90
II M-5	1,12-Benzo-perylene	R	U		Separable by gravity or sand filtration.		90
II M-6	Benzo(a)-pyrene	R	U		Separable by gravity or sand filtration.		90
II M-7	2-Chloro-Napthalene	R	U	0.1-0.9 ppm	Precipitation w/alum.		90
II M-8	Chrysene	R	U		Separable by gravity or sand filtration.		90
II M-9	Naphthalene	R	U		Separable by gravity or sand filtration.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Chemical Precipitation (II)
Chemical Classification: Polynuclear Aromatics (M)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
II M-10	2,3-o-Phenylene Pyrene	R	U		Separable by gravity or sand filtration.		90
II M-11	Pyrene	R	U		Separable by gravity or sand filtration.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III A-1	Ethanol	B	P	1000 ppm @ 150 mls	21.4% reduction w/CA membrane 70.3% reduction w/C-PEI membrane.	CA and C-PEI membranes operated at 600 psig and room temperature.	18
III A-2	Ethanol	L	P	1000 ppm	80-100% reduction w/NS-200 membrane; 60-80% reduction w/NS-100-T membrane; 40-60% reduction w/AP & NS-100 membranes; 20-40% reduction w/ CA3 & B-9 membranes; <20% reduction w/CA, CA-T, CAB, PBI, SPPO & B-10 membranes.		30
III A-3	Methanol	B	P	1000 ppm @ 150 mls	7.3% reduction w/CA membrane; 20% reduction w/C-PEI membrane.	See IIIA-1 for comments.	18
III A-4	Methanol	L	P	1000 ppm	20-40% reduction w/B-9, NS-200 & NS-100T membranes; <20% reduction w/B-10, AP, SPPO, PBI, NS-100 membranes; 0% reduction w/CA, CA-T, CAB & CA3 membranes.		30
III A-5	i-Propanol	B	P	1000 ppm @ 150 mls	40.9% reduction w/CA membrane 88.1% reduction w/C-PEI membrane.	See IIIA-1 for comments.	18
III A-6	i-Propanol	L	P	1000 ppm	80-100% reduction w/NS-100, NS-100T, NS-200, AP, B-9 & B-10 membranes; 40-60% reduction w/CA-T, CA & CA3 membranes; 20-40% reduction w/ SPPO, PBI & CAB membranes.		30

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III B-1	Acetic Acid	B	P	1000 ppm @ 150 ml	32% reduction w/CA membrane; 68.1% reduction w/C-PEI membrane.	CA and C-PE1 membranes operated at 600 psig & room temperature.	18
III B-2	Acetic Acid	L	P	1000 ppm	60-80% reduction w/AP, NS-200 & NS-100T membranes; 40-60% reduction w/NS-100 membrane; 20-40% reduction w/SPPO, B-9 & B-10 membranes; <20% reduction w/PBI, CA3, CAB, CA-T & CA membranes.		30
III B-3	Acetone	B	P	1000 ppm @ 150 ml	14.9% reduction w/CA membrane 81.8% reduction w/C-PEI membrane.	See IIIB-1 for comments.	18
III B-4	Acetone	L	P	1000 ppm	80-100% reduction w/NS-200 & NS-100-T membrances; 60-80% reduction w/AP & NS-100 membranes; 40-60% reduction w/ B-9 & B-10 membranes; 20-40% reduction w/CA3 membrane; <20% reduction w/SPPO, PBI, CAB, CA-T & CA membranes.		30
III B-5	Dimethyl Sulfoxide	B	P	250 ppm	88.2% reduction w/CA membrane; 63.3% reduction w/C-PEI membrane.	See IIIB-1 for comments.	18
III B-6	Formaldehyde	B	P	1000 ppm	21.9% reduction w/CA membrane; 56.7% reduction w/ C-PEI membrane.	See IIIB-1 for comments.	18
III B-7	Formaldehyde	L	P	1000 ppm	60-80% reduction w/NS-200 membrane; 40-60% reduction w/AP, NS-100, CAB & NS-100-T		30

(continued)

TABLE C-1(continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
III B-7 cont					membranes; 20-40% reduction w/B-9, CA3 & CA-T membranes; <20% reduction w/CA, PBI, SPPO & B-10 membranes.		
III B-8	Glycerol	B	P	1000 ppm @ 150 ml	89.9% reduction w/CA membrane; 97.8% reduction w/C-PEI membrane.	See IIIB-1 for comments.	18
III B-9	Glycerol	L	P	1000 ppm	80-100% reduction w/CA-T, CAB, CA3, NS-100, NS-100T, NS-200, AP, B-9 & B-10 membranes; 60-80% reduction w/CA membrane; 40-60% reduction w/PBI membrane; 20-40% reduction w/SPPO membrane		30
III B-10	Methyl Acetate	B	P	1000 ppm @ 150 ml	4.6% reduction w/CA membrane 76.1% reduction w/C-PEI membrane.	See IIIB-1 for comments.	18
III B-11	Methyl Acetate	L	P	1000 ppm	60-80% reduction w/NS-200, NS-100-T & NS-100 membranes; 40-60% reduction w/B-9 membrane; 20-40% reduction w/B-10, AP & CA-T membranes; <20% reduction w/SPPO,PBI & CA3 membranes; 0% reduction w/CA & CAB membranes.		30

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III C-1	Aniline	B	P	1000 ppm @ 150 ml	-3.4% reduction w/CA membrane; 82.9% reduction w/C-PEI membrane.	CA & C-PEI membranes operated at 600 psig & room temperature.	18
III C-2	Aniline	L	P	1000 ppm	80-100% reduction w/NS-100-T membrane; 60-80% reduction w/B-10, NS-200 & NS-100 membranes; 40-60% reduction w/B-9 membrane; 20-40% reduction w/AP, CA3 & CAB membranes; <20% reduction w/SPPO & PBI membranes; 0% reduction w/CA & CA-T membranes.		30

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III D-1	Chlorobenzene	R	U	$\leq$360 ppm	97-100% reduction @ 50-100 kg/cm^2.		90
III D-2	Dinitrobenzene	B	P	30 ppm @ 150 ml	7.2% reduction w/CA membrane 81.4% reduction w/C-PEI membrane.	CA & C-PEI membranes operated @ 600 psig & room temperature.	18
III D-3	2,4-Dinitrophenylhydrazine	B	P	30 ppm @ 150 ml	3.2% reduction w/CA membrane 91.1% reduction w/C-PEI membrane.	See IIID-2 for comments.	18
III D-4	Hexachlorobenzene	R	U	638 ppm	52% reduction.		90
III D-5	Hydroquinone	B	P	1000 ppm	-2.5% reduction w/CA membrane 79.7% reduction w/C-PEI membrane.	CA & C-PEI membranes operated @ 600 psig & room temperature.	18
III D-6	Hydroquinone	L	P	1000 ppm	80-100% reduction w/AP & NS-200 membranes; 60-80% reduction w/B-10, NS-100-T & NS-100 membranes; 40-60% reduction w/B-9 membrane; 20-40% reduction w/SPPO & CAB membranes; <20% reduction w/PBI & CA3 membranes; 0% reduction w/CA & CA-T membranes		30

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Ethers (E)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III E-1	bis(2-Chloro-isopropyl) Ether	B	P	250 ppm @ 150 ml	37.3% reduction w/CA membrane; 94% reduction w/C-PEI membrane.	CA & C-PEI membrane operated at 600 psig & room temperature.	18
III E-2	Diethyl Ether	B	P	1000 ppm @ 150 ml	9.5% reduction w/CA membrane 90.3% reduction w/C-PEI membrane.	See IIIE-1 for comments.	18
III E-3	Ethyl Ether	L	P	1000 ppm	80-100% reduction W/AP, NS-200, NS-100-T & NS-100 membranes; 60-80% reduction w/B-10 membrane; 40-60% reduction w/B-9, SPPO & PBI membranes; 20-40% reduction CAB & CA3 membranes; <20% reduction w/CA-T & CA membranes.		30

(continued)

TABLE C-1(continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III F-1	Trichloroacetic Acid	B	P	250 ppm @ 150 ml	49.3% reduction w/CA membrane; 25% reduction w/C-PEI membrane.	CA & C-PEI membrane operated at 600 psig & room temperature.	18

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III G-1	Barium	B	P	0.75 ppm	>86.7% reduction w/CA membrane	CA membrane operated at 400 psig & 16-22°C.	18
				0.85 ppm	>88.2% reduction w/CA membrane		
				9.15 ppm	97.8% reduction w/CA membrane		
				7.05 ppm	>98.6% reduction w/CA membrane		
III G-2	Cadmium	B	P	0.10 ppm	90% reduction w/CA membrane	See IIIG-1 for comments.	18
				0.10 ppm	90% reduction w/CA membrane		
				0.96 ppm	99% reduction w/CA membrane		
				1.0 ppm	98.7% reduction w/CA membrane		
III G-3	Chromic Acid	L,C	I	200 ppm @ 20 gal/hr	85% rejection over 200 hrs w/polybenzimidazole membrane.	Polybenzimidazole membrane operated at 1500 psl.	24
III G-4	Chromium	B	P	12.5 ppm	97.6% reduction W/C-PEI membrane @ pH=8.0.	C-PEI membrane operated at 600 psig & room temperature.	18
				12.5 ppm	91.3% reduction w/C-PEI membrane @ pH=11.0.		
III G-5	Chromium	B	P	0.94 ppm	96.9% reduction w/CA membrane	See IIIG-1 for comments.	18
				1.01 ppm	95.0% reduction w/CA membrane		
				8.65 ppm	93.2% reduction w/CA membrane		
				9.35 ppm	85.1% reduction w/CA membrane		
III G-6	Copper	B	P	12.5 ppm	99.9% reduction w/C-PEI membrane @ pH=8.0 & 11.0.	See IIIG- 4 for comments.	18
III G-7	Copper	B	P	0.65 ppm	97% reduction w/CA membrane	See IIIG- 1 for comments.	18
				0.7 ppm	94.8% reduction w/CA membrane		
				6.25 ppm	99.6% reduction w/CA membrane		
				6.5 ppm	99.2% reduction w/CA membrane		
III G-8	Iron	B	P	12.5 ppm	100% reduction w/C-PEI membrane @ pH=8.0 & 11.0.	See IIIG-4 for comments.	18

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III G-1	Lead	B	P	12.5 ppm	100% reduction w/C-PEI membrane @ pH=8.0 & 11.0.	See IIIG-4 for comments.	18
III G-2	Lead	B	P	0.95 ppm	99.5% reduction w/CA membrane	See IIIG-1 for comments.	18
				1.1 ppm	97.8% reduction w/CA membrane		
				4.75 ppm	99.9% reduction w/CA membrane		
				9.3 ppm	97.8% reduction w/CA membrane		
III G-3	Nickel	B	P	12.5 ppm	92.8% reduction w/C-PEI membrane @ pH=8.0.	See IIIG-4 for comments.	18
				12.5 ppm	97.6% reduction w/C-PEI membrane @ pH=11.0.		
III G-4	Zinc	B	P	12.5 ppm	96.6% reduction w/C-PEI membrane @ pH=8.0.	See IIIG-1 for comments.	18
				12.5 ppm	100% reduction w/C-PEI membrane @ pH=11.0.		
III G-5	Zinc	B	P	9.4 ppm	96.9% reduction w/CA membrane	See IIIG-1 for comments.	18
				10.0 ppm	98.6% reduction w/CA membrane		
				31.4 ppm	98.8% reduction w/CA membrane		
				32.8 ppm	99.5% reduction w/CA membrane		

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III J-1	Aldrin	B	P	142 µg	100% reduction w/CA membrane 100% reduction w/C-PEI membrane.	CA & C-PEI membranes operated at 600 psig & room temperature.	18
III J-2	Atrazine	B	P	1102 µg	84% reduction w/CA membrane 97.8% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18
III J-3	Captan	B	P	689 µg	98.8% reduction w/CA membrane 100% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18
III J-4	DDE	B	P	69 µg	100% reduction w/CA membrane 100% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18
III J-5	DDT	B	P	42 µg	100% reduction w/CA membrane 100% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18
III J-6	Diazinon	B	P	474 µg	98.3% reduction w/CA membrane 88.1% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18
III J-7	Dieldrin	B	P	321 µg	99.9% reduction w/CA membrane 100% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18
III J-8	Heptachlor	B	P	145 µg	100% reduction w/CA & C-PEI membranes.	See IIIJ-1 for comments.	18
III J-9	Heptachlor-epoxide	B	P	307 µg	99.8% reduction w/CA & C-PEI membranes.	See IIIJ-1 for comments.	18
III J-10	Lindane	B	P	506 µg	99.5% reduction w/CA membrane 99.0% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III J-11	Malathion	B	P	1058 µg	99.2% reduction w/CA membrane 99.7% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18
III J-12	Methyl Parathion	B	P	913 µg	99.6% reduction w/CA & C-PEI membranes.	See IIIJ-1 for comments.	18
III J-13	Parathion	B	P	747 µg	99.9% reduction w/CA membrane 99.8% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18
III J-14	Randox	B	P	327 µg	72% reduction w/CA membrane 98.6% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18
III J-15	Trifluralin	B	P	1579 µg	99.7% reduction w/CA membrane 100% reduction w/C-PEI membrane.	See IIIJ-1 for comments.	18

(continued)

TABLE C-1 (continued)

Concentration Process: Reverse Osmosis (III)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
III K-1	2-Chlorophenol	R	U		66.3% reduction.		90
III K-2	4-Nitrophenol	R	U		Removable by reverse osmosis.		90
III K-3	Phenol	R	U		17.8% reduction.		90
III K-4	Phenol	B	P	1000 ppm	-5.7% reduction w/CA membrane 76.5% reduction w/C-PEI membrane.		18
III K-5	Phenol	P	S	1-100mg/1 each of phenol, resorcinol, o-cresol, catechol	In excess of 90% separation at pH 8-10 w/optimum at pH 9 at flux rate of about 70 gpd/ft^2. Results indicate that hyperfiltration (reverse osmosis) produced higher rejection & flux rates than ultrafiltration. Increasing pressure improves rejection slightly & flux rate greatly. Increasing pH increased rejection w/little effect on flux rate. Conc. had little effect on either rejection or flux rate.	Size: 60-130 gpd/ft^2 flux. Duration: 0-60hrs Pressure: 250-950 psig. Velocity: 15 fps. Membranes: Hydrous Zr (IV) oxide-PAA membrane on carbon stainless steel & selas support.	54

(continued)

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TABLE C-1 (continued)

Concentration Process: Ultrafiltration (IV)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IV D-1	TNT (accounted for 90% of TOC)	L,C	I+P	20 ppm TOC @ pH=11.0	80% TOC reduction by PSAL (Millipore) noncellulose membrane.	TDS conc. was 1200 ppm. Average pressure: 25-60 psi. Estimated cost for full scale operation was $1.85/1000 gal	10
				200 ppm TOC @ pH=11.0	93% TOC reduction by PSAL (Millipore) noncellulose membrane.		

(continued)

TABLE C-1 (continued)

Concentration Process: Ultrafiltration (IV)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IV G-1	Copper	C,P	I	0.44 ppm	0.08 ppm effluent conc.		59
IV G-2	Iron	C,P	I	6.8 ppm	1.0 ppm effluent conc.		59
IV G-3	Manganese	C,P	I	4.9 ppm	0.52 ppm effluent conc.		59
IV G-4	Zinc	C,P	I	1.8 ppm	0.38 ppm effluent conc.		59

(continued)

TABLE C-1 (continued)

Concentration Process: Ultrafiltration (IV)
Chemical Classification: Phenols (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IV G-1	Phenols	P	S	1-100 ppm each of phenol, resorcinol, o-cresol, catechol	Maximum rejection was 75% at pH 10; rejection increased as pH increased. Ionic state of solute rather than membrane material controlled rejection rate. Increased temp resulted in increased flux rate but rejection rate was only slightly affected. Solute rejection was not affected by length of operating time.	Size: 30-160 gpd/ft^2 flux. Duration: 0-200hr Pressure: 200 psig. Velocity: 15 fps Temp: 25-55°C Hydrous Zr(IV) oxide, silicate membranes.	54

(continued)

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TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VB-1	Acrylonitrile	R	U		Flash vaporization from water by high pressure discharge.		90

(continued)

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TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
VD-1	Benzene	R	U		Air & steam strippable.		90
VD-2	Benzene	C,P	S	0.13 gpm flow	95-99% reduction by steam stripping.	Estimated cost of $3.35/1000 gal based on 0.03 MGD	13
VD-3	Chlorobenzene	R	U		Steam strippable.		90
VD-4	Chlorobenzene	F,C	D	0.66 M^3/s flow	60% reduction by air stripping.		64
VD-5	m-Dichlorobenzene o-	R	U		Air & steam strippable.		90
VD-6	p-Dichlorobenzene	R	U		Steam strippable.		90
VD-7	1,2-Dichlorobenzene	F,C	D	0.66 M^3/s flow	70% reduction by air stripping.		64
VD-8	1,3-Dichlorobenzene	F,C	D	0.66 M^3/s flow	80% reduction by air stripping.		64
VD-9	1,4-Dichlorobenzene	F,C	D	0.66 M^3/s flow	90% reduction by air stripping.		64
VD-10	Ethylbenzene	F,C	D	0.66 M^3/s flow	80% reduction by air stripping.		64
VD-11	Ethylbenzene	R	U		Air & steam strippable.		90
VD-12	Ethylbenzene	P,C	S	0.13 gpm flow	86-93% reduction by steam stripping.	See VD- 2 for comments.	13
VD-13	Hexachlorobenzene	R	U		Steam strippable.		64

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TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VD-14	Nitrobenzene	R	U	450-2160 ppm	Steam strippable.		64
VD-15	Styrene	P,C	S	0.13 gpm flow	98-99% reduction by steam stripping.	See VD-2 for comments.	13
VD-16	Toluene	P,C	S	0.13 gpm flow	73-92% reduction	See VD-2 for comments.	13
VD-17	Toluene	R	U		Air & steam strippable.		90
VD-18	1,2,4-Trichlorobenzene	F,C	D	0.66 M^3/s	50% reduction by air stripping.		64
VD-19	1,2,4-Trichlorobenzene	R	U		Steam strippable.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study			Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.					
VF-1	Bromodichloromethane	R	U		Air & steam strippable.				90
VF-2	Bromomethane	R	U		Air strippable.			Gas at STP	90
VF-3	Chloral	P,C	I	693.2 ppm @ 250ml/min feed rate	Overhead flow (% of feed)	Overhead Conc. (ppm)	Bottom Conc. (ppm)	Water quality: TOC - 9022 ppm COD - 15100 ppm pH - 0.1 acidity - 102312 ppm Cl-116,127 ppm Numerous other halogens present.	95
					2.3	1213.0	171.9		
					2.8	1163.6	177.1		
					5.1	1185.5	172.6		
					2.3 with 1.4:1 reflux to overhead ratio	2332.3	464.3		
					2.5 with 0.9:1 reflux to overhead ratio	2301.6	434.4		
VF-4	Chloroethane	R	U		90% evaporation from H_2O-79 min with air stripping.				90
VF-5	Chloroethylene	R	U		Air strippable			Gas at STP	90
VF-6	Chloroform	P,C	I	140.3 ppm @ 250ml/min feed rate	Overhead flow (% of feed)	Overhead Conc. (ppm)	Bottom Conc. (ppm)	See VF-3 for comments.	95
					2.3	1185.1	0		
					2.8	882.4	0		
					5.1	838.3	0		

(continued)

TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study			Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.					
VF-6 cont					Overhead flow (% of feed)	Overhead Conc. (ppm)	Bottom Conc. (ppm)		
					2.3 with 1.4:1 reflux to overhead ratio	412.3	0		
					2.5 with 1.4:1 reflux to overhead ratio	1124.3	64.7		
VF-7	Chloromethane	R	U		Air strippable.			Gas at STP	90
VF-8	Dibromochloromethane	R	U		Air & steam strippable.				90
VF-9	1,1-Dichloroethane	R	U		90% evaporation from H_2O - 109 min with air stripping.				90
VF-10	1,2-Dichloroethane	R	U		Air & steam strippable.				90

(continued)

TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study			Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.					
VF-11	1,2-Dichloroethane	P,C	I	1583.3ppm @ 250 ml/min feed rate	Overhead flow (% of feed)	Overhead Conc. (ppm)	Bottom Conc. (ppm)	See VF-3 for comments.	95
					2.3	350.8	373.7		
					2.8	269.7	1255.4		
					5.1	465.0	14.8		
					2.3 with 1.4:1 reflux to overhead ratio	1320.9	16.1		
					2.5 with 0.9:1 reflux to overhead ratio	679.9	0		
VF-12	1,1-Dichloroethylene	R	U		Air & steam strippable.				90
VF-13	1,2-trans-Dichloroethylene	R	U		90% evaporation from H_2O - 83 min with air stripping.				90
VF-14	1,1-Dichloroethylene	P,C	I	61.5 ppm @ 250 ml/min feed rate	Overhead flow (% of feed)	Overhead Conc. (ppm)	Bottom Conc. (ppm)	See VF-3 for comments.	95
					2.3	124.4	32.8		
					5.1	111.2	0		
					2.5 with 0.9:1 reflux to overhead ratio	179.9	0		

(continued)

TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study			Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.	Overhead flow (% of feed)	Overhead Conc. (ppm)	Bottom Conc. (ppm)		
VF-15	Dichloromethane	P,C	I	800.9 ppm @ 250 ml/min feed rate	2.3	3511.8	114.1	See VF-3 for comments.	95
					2.8	3277.0	89.5		
					5.1	2736.5	175.6		
					2.3 with 1.4:1 reflux to overhead ratio	1183.0	296.3		
					2.5 with 0.9:1 reflux to overhead ratio	5159.9	131.7		

(continued)

TABLE C-1(continued)

Concentration Process: **Stripping (V)**
Chemical Classification: **Halocarbons (F)**

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VF-16	Dichloromethane	R	U		90% evaporation from H_2O-60 min with air stripping.		90
VF-17	1,2-Dichloropropane	R	U		Air & steam strippable.		90
VF-18	1,2-Dichloropropylene	R	U		Air & steam strippable.		90
VF-19	Ethylene Dichloride	P,C	I	1593 ppm @ 250ml/min feed rate	Overhead flow (% of feed) / Overhead Conc. (ppm) / Bottom Conc. (ppm) 2.3 / 4383.5 / 42.2 2.8 / 4105.5 / 64.5 5.1 / 4731.5 / 43.1 2.3 with 1.4:1 reflux to overhead flow / 3654.5 / 38.6 2.5 with 0.9:1 reflux to overhead ratio / 5541.3 / 436.4	See VF-3 for comments.	95

(continued)

TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VF-20	Ethylene Dichloride	P,C	I	Average conc. of 4512 ppm @ ave. feed rate of 325ml/min	Average Overhead flow (ml/min) / Average Overhead Conc. (ppm) / Average Bottom Conc. (ppm) 20.8 / 21.6 / 20.3	Wastewater quality: COD - 615 ppm TC - 1703 ppm pH - 11.2 Alkalinity - 4840 ppm Cl - 6564 ppm	95
VF-21	Ethylene Dichloride	P,C	I	8700 ppm @ 10 gpm flow rate	99% reduction with average stripping tower temperature of 221° F.		66
VF-22	Hexachloro-butadiene	R	U		Air & steam strippable.		90
VF-23	Hexachloro-cyclopenta-diene	R	U		Polymerizes with heat.		90
VF-24	Perchloro-ethylene	P,C	I	14.9 ppm @ 250ml/min feed rate	Overhead flow (% of feed) / Overhead Conc. (ppm) / Bottom Conc. (ppm) 2.3 / Not reported / 6.8 2.8 / 50.2 / 0 2.5 with 0.9:1 reflux to overhead ratio / 9.6 / 0	See VF- 3 for comments.	95
VF-25	1,1,1,2-Tetra-chloroethane	P,C	I	512.8ppm @ 250ml/min feed rate	Overhead flow (% of feed) / Overhead Conc. (ppm) / Bottom Conc. (ppm) 2.3 / 189.8 / 0 2.8 / 393.8 / 0.84	See VF- 3 for comments.	95

(continued)

TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study			Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.	Overhead flow (% of feed)	Overhead Conc. (ppm)	Bottom Conc. (ppm)		
VF-25 cont					5.1	22.7	0		
					2.3 with 1.4:1 reflux to overhead ratio	25.8	0.5		
					2.5 with 0.9:1 reflux to overhead ratio	392.5	1.6		
VF-26	1,1,2,2-Tetrachloroethane	P,C	I	14.9 ppm @ 250ml/min feed rate	2.3	14.9	32.7	See VF-3 for comments.	95
					2.8	121.7	49.5		
					5.1	444.4	78.4		
					2.3 with 1.4:1 reflux to overhead ratio	8.7	0		
					2.5 with 0.9:1 reflux to overhead ratio	24.2	0.1		

(continued)

TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Halocarbons (F)

<table>
<tr><th rowspan="2">No.[a]</th><th rowspan="2">Chemical[b]</th><th colspan="3">Description of Study</th><th rowspan="2">Results of Study</th><th rowspan="2">Comments</th><th rowspan="2">Ref.</th></tr>
<tr><th>Study Type[c]</th><th>Waste Type[d]</th><th>Influent Char.</th></tr>
<tr><td>VF-27</td><td>Tetrachloroethylene</td><td>R</td><td>U</td><td></td><td>Air & steam strippable, 90% evaporation from H_2O - 72 min</td><td></td><td>90</td></tr>
<tr><td>VF-28</td><td>Tetrachloromethane</td><td>R</td><td>U</td><td></td><td>Air & steam strippable, 90% evaporation from H_2O - 97 min</td><td></td><td>90</td></tr>
<tr><td>VF-29</td><td>Tribromomethane</td><td>R</td><td>U</td><td></td><td>Air & steam strippable.</td><td></td><td>90</td></tr>
<tr><td>VF-30</td><td>1,1,1-Trichloroethane</td><td>R</td><td>U</td><td></td><td>Air & steam strippable.</td><td></td><td>90</td></tr>
<tr><td>VF-31</td><td>1,1,1-Trichloroethane</td><td>P,C</td><td>I</td><td>50.92 ppm @ 250 ml/min feed rate</td><td><table>
<tr><th>Overhead flow (% of feed)</th><th>Overhead Conc. (ppm)</th><th>Bottom Conc. (ppm)</th></tr>
<tr><td>2.5 with 0.9:1 reflux to overhead ratio</td><td>173.4</td><td>41.6</td></tr>
</table></td><td>See VF-3 for comments.</td><td>95</td></tr>
<tr><td>VF-32</td><td>1,1,2-Trichloroethane</td><td>R</td><td>U</td><td></td><td>Air & steam strippable, 90% evaporation from H_2O- 102 min</td><td></td><td>90</td></tr>
<tr><td>VF-33</td><td>1,1,2-Trichloroethane</td><td>P,C</td><td>I</td><td>14.14 ppm @ 250 ml/min feed rate</td><td><table>
<tr><th>Overhead flow (% of feed)</th><th>Overhead Conc. (ppm)</th><th>Bottom Conc. (ppm)</th></tr>
<tr><td>2.3</td><td>24.6</td><td>0.19</td></tr>
<tr><td>2.8</td><td>34.0</td><td>0</td></tr>
<tr><td>5.1</td><td>76.5</td><td>0</td></tr>
<tr><td>2.3 with 1.4:1 reflux to overhead ratio</td><td>42.4</td><td>0</td></tr>
</table></td><td>See VF-3 for comments.</td><td>95</td></tr>
</table>

(continued)

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TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VF-33 cont					Overhead flow (% of feed) / Overhead Conc. (ppm) / Bottom Conc. (ppm) 2.5 with 0.9:1 reflux to overhead ratio / 66.1 / 0		
VF-34	Trichloroethylene	R	U		Air & steam strippable, 90% evaporation from H_2O-63 min.		90
VF-35	Trichloroethylene	P,C	I	250ml/min feed rate	Overhead flow (% of feed) / Overhead Conc. (ppm) / Bottom Conc. (ppm) 2.3 / 640.8 / 34.2 2.8 / 567.0 / 0 5.1 / 627.4 / 22.7 2.3 with 1.4:1 reflux to overhead ratio / 640.8 / 37.2 2.5 with 0.9:1 reflux to overhead ratio / 644.5 / 0	See VF-3 for comments.	95
VF-36	Trichloromethane	R	U		Air & steam strippable, 90% evaporation from H_2O-62 min.		90

(continued)

TABLE C-1(continued)

Concentration Process: Stripping (V)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VK-1	Phenol	R	U		Steam strippable.		90
VK-2	Chlorophenol	R	U		Steam strippable.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Stripping (V)
Chemical Classification: Polynuclear Aromatic (M)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VM-1	Naphthalene	R	U		Air stripping by 50:1 volumes of air.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII A-1	Ethanol	L,C	I	286 ppm	7% reduction.	Extraction of neutralized oxychlorination wastewater using 2-ethylhexanol (S/W=0.106); RDC extractor used.	27

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII B-1	Acrolein	R	U		Extractable w/xylene. Solvent recovery by azeotropic distillation.		90
VII B-2	Acrylonitrile	R	U		Extractable w/ethyl ether.		90
VII B-3	Isophorone	R	U		Extractable w/ethyl ether.		90
VII B-4	Methyl Ethyl Ketone	L,C	I	12200ppm @ 3.21 gal/hr	69% reduction.	Sequential extraction of waste water from lube-oil refining using butyl acetate (S/W=0.10) & isobutylene (S/W=0.101); RDC extractor used.	27
VII B-5	Methyl Ethyl Ketone	L,C	I	12200ppm @ 3.21 gal/hr	88% reduction.	Sequential extraction of waste water from lube-oil refining using butyl acetate (S/W=0.10) & isobutylene (S/W=0.101); RDC extractor used.	27

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII D-1	Benzene	R	U		Extractable w/suitable solvent.		90
VII D-2	Benzene	L,C	I	290 ppm @ 3 gal/hr	97% reduction.	Extraction of wastewater from styrene manufacture using isobutylne (S/W=0.107); RDC extractor used.	27
VII D-3	Benzene	L,C	I	71 ppm @ 4.6 gal/hr	96% reduction.	Extraction of ethylene quench wastewater using isobutylene (S/W=0.101) RDC extractor used.	27
VII D-4	Benzene	L,C	I	81 ppm @ 4.6 gal/hr	97% reduction.	Extraction of ethylene quench wastewater using isobutane (S/W=0.097); RDC extractor used.	27
VII D-5	Chlorobenzene	R	U	600 ppm	3 ppm effluent conc. using chloroform solvent.		90
VII D-6	o-Dichlorobenzene m- p-	R	U		Extractable w/suitable solvent.		90
VII D-7	2,4-Dinitrotoluene	R	U		Extractable w/suitable solvent.		90
VII D-8	2,6-Dinitrotoluene	R	U		Extractable w/suitable solvent.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII D-9	Ethylbenzene	L,C	I		97% reduction.	See VIID-2 for comments.	27
VII D-10	Ethylbenzene	R	U		Extractable w/suitable solvent.		90
VII D-11	Hexachlorobenzene	R	U		Extractable w/suitable solvent.		90
VII D-12	Nitrobenzene	R	U		Extractable w/suitable solvent.		90
VII D-13	Styrene	L,C	I		>93% reduction.	See VIID-2 for comments.	27
VII D-14	Toluene	R	U		Extractable w/suitable solvent.		90
VII D-15	Toluene	L,C	I	41-44ppm @ 4.6 gal/hr	94%-96% reduction.	See VIID-3 & 4 for comments.	27
VII D-16	1,2,4-Trichlorobenzene	R	U		Extractable w/suitable solvent.		90
VII D-17	Xylene	L,C	I		>97% reduction.	See VIID-3 for comments.	27
VII D-18	Xylene	L,C	I		>97% reduction.	See VIID-4 for comments.	27

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Ethers (E)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII E-1	bis-Chloroethyl Ether	R	U		Extractable w/ethyl ether & benzene.		90
VII E-2	bis-Chloroisopropyl Ether	R	U		Extractable w/ethyl ether & benzene.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII F-1	Bromodichloromethane	R	U		Soluble in most organics.		90
VII F-2	Bromomethane	R	U		Soluble in most organics.		90
VII F-3	Chloral Hydrat	L,C	I	15200 ppm	49% reduction.	Extraction of neutralized oxychlorination wastewater using 2-ethylhexanol (S/W=0.106) RDC extractor used.	27
VII F-4	Chloroethane	R	U		Extractable w/alcohols and aromatics.		90
VII F-5	Chloroethylene	R	U		Soluble in most organics.		90
VII F-6	Chloromethane	R	U		Soluble in most organics.		90
VII F-7	Dibromochloromethane	R	U		Extractable w/organics, ethers and alcohols.		90
VII F-8	Dichlorodifluoromethane	R	U		Extractable w/organics, ethers and alcohols.		90
VII F-9	1,1-Dichloroethane	R	U		Extractable w/alcohols and aromatics.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII F-1	1,2-Dichloroethane	R	U		Extractable w/alcohols and aromatics.		90
VII F-2	Dichloroethylene	L,B	I	49 ppm	Kerosene effluent conc. - 2 ppm; C_{10}-C_{12} effluent conc. - 1 + ppm	Solvent extraction used separatory funnel w/kerosene & C_{10}-C_{12} hydrocarbon solvents at 7:1 solvent to wastewater ratio.	95
VII F-3	Dichloroethylene	L,C	I	1500 ppm	>99% reduction.	See VIIF-3 for comments.	27
VII F-4	1,1-Dichloroethylene	R	U		Extractable w/alcohols, aromatics and ethers.		90
VII F-5	1,2-trans-Dichloroethylene	R	U		Soluble in most organics.		90
VII F-6	Dichloromethane	R	U		Soluble in most organics.		90
VII F-7	1,2-Dichloropropane	R	U		Soluble in most organics.		90
VII F-8	1,2-Dichloropropylene	R	U		Soluble in most organics.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII F-9	Ethyl Chloride	L,B	I	3 ppm	Kerosene effluent conc. - 1 ppm; C_{10}-C_{12} hydrocarbon effuent - 1 + ppm.	Solvent extraction used separatory funnel w/ kerosene & C_{10}-C_{12} hydrocarbon solvents at 7:1 solvent to wastewater ratio.	95
VII F-10	Ethylene Chlorohydrin	L,C	I	1640 ppm	21% reduction.	See VIIF-3 for comments.	27
VII F-11	Ethylene Dichloride	L,B	I	320 ppm	No detectable conc. in kerosene effluent; C_{10}-C_{12} hydrocarbon effluent - 1 + ppm.	See VIIF-9 for comments.	95
VII F-12	Ethylene Dichloride	P,C	I	23-1804 ppm @ 2.76-3.76 1/min	A 5.5:1 water to solvent ratio gave 94-96% reduction. C_{10}-C_{12} paraffin solvent at 5:1 to 16.5:1 water to solvent ratio showed 94-99% reduction	Wastewater contained other halocarbons including 30-350 ppm 1,1,2-trichloroethane and 5-197 ppm 1,1,2,2-tetrachloroethane. A 532 1/min extractor w/1000 ppm influent estimated to have a capital cost of $315,000 and total annual cost of $143,000 including credit for recovered EDC.	95
VII F-13	Hexachlorobutadiene	R	U		Soluble in most organics.		90
VII F-14	Hexachloroethane	R	U		Extractable w/aromatics, alcohols and ethers		90

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII F-15	Pentachloroethane	L,B	I	10 ppm	Kerosene effluent conc. - 2 ppm; No detectable conc. in C_{10}-C_{12} hydrocarbon effluent.	See VIIF-9 for comments.	95
VII F-16	Perchloroethylene	L,B	I	14 ppm	Kerosene effluent conc. - 2 ppm; C_{10}-C_{12} hydrocarbon effluent conc. - 1 ppm.	See VIIF-9 for comments.	95
VII F-17	Tetrachloroethane	L,B	I	148 ppm	Kerosene effluent conc. - 7 ppm; C_{10}-C_{12} hydrocarbon effluent conc. - 6 ppm.	See VIIF-9 for comments.	95
VII F-18	1,1,2,2-Tetrachloroethane	R	U		Extractable w/aromatics, alcohols and ethers.		90
VII F-19	Tetrachloroethylene	R	U		Soluble in most organics.		90
VII F-20	Tetrachloromethane	R	U		Soluble in most organics.		90
VII F-21	Tribromomethane	R	U		Soluble in most organics.		90
VII F-22	Trichloroethane	L,B	I	75 ppm	Kerosene effluent conc. - 2 ppm; C_{10}-C_{12} hydrocarbon effluent conc. - 1 ppm.	See VIIF-9 for comments.	95
VII F-23	1,1,1-Trichloroethane	R	U		Extractable w/alcohols and aromatics.		90
VII F-24	1,1,2-Trichloroethane	R	U		Extractable w/aromatics, methanol and ethers.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII F-25	Trichloro-ethylene	L,B	I	24 ppm	Kerosene effluent conc.- 6 ppm; C_{10}-C_{12} hydrocarbon effluent conc. - 5 ppm.	See VIIF- 9 for comments.	95
VII F-26	Trichloro-ethylene	R	U		Soluble in most organics.		90
VII F-27	Trichloro-fluoromethane	R	U		Extractable w/alcohol, ether and organics.		90
VII F-28	Trichloro-methane	R	U		Soluble in most organics.		90
VII F-29	Vinylidene Chloride	L,B	I	13 ppm	Kerosene effluent conc. - 1 ppm; C_{10}-C_{12} effluent conc. - 1 ppm.	See VIIF- 9 for comments.	95

(continued)

TABLE C-1(continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII G-1	Mercury	R	U	2 ppm	99% reduction w/high molecular weight amines & quartenary salts.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII K-1	4-Chloro-3-Methylphenol		U		Extractable w/benzene, alcohol and nitrobenzene		90
VII K-2	2-Chlorophenol	R	U		Extractable w/Diisopropylether, benzene, butylacetate, and nitrobenzene		90
VII K-3	m-Cresol p-	L,C	I	291 ppm	91% reduction.	Extraction of evaporator condensate from spent caustic processing using isobutylene (S/W=1.8); spray extractor used.	27
VII K-4	o-Cresol	L,C	I	307 ppm	90% reduction.	See VIIK-3 for comments.	27
VII K-5	o-Cresol	L,C	I	890 ppm @ 3.21 gal/hr	99.9% reduction.	Sequential extraction of wastewater from lube-oil refining using butyl acetate (S/W=0.100) & isobutylene (S/W=0.101); RDC extractor used.	27
VII K-6	o-Cresol	L,C	I	890 ppm @ 3.21 gal/hr	99.9% reduction.	Sequential extraction of wastewater from lube-oil refining using butyl acetate (S/W=0.30) & isobutylene (S/W=0.101): RDC extractor used.	27

(continued)

TABLE C-1(continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII K-7	2,4-Dichlorophenol	R	U		Extractable w/benzene, alcohol and nitrobenzene.		90
VII K-8	2,4-Dimethylphenol	R	U		Extractable w/benzene and alcohol.		90
VII K-9	4,6-Dinitro-2-Methylphenol	R	U		Extractable w/benzene and acetone.		90
VII K-10	2,4-Dinitrophenol	R	U		Extractable w/benzene and alcohol.		90
VII K-11	2-Nitrophenol	R	U		Extractable w/benzene and alcohol.		90
VII K-12	4-Nitrophenol	R	U		Extractable w/benzene and alcohol.		90
VII K-13	Pentachlorophenol	R	U		Extractable w/benzene and alcohol and nitrobenzene.		90
VII K-14	Phenol	R	U		Extractable w/diisopropylether, benzene, butylacetate and nitrobenzene.		90
VII K-15	Phenol	L,C	I	67 ppm @ 4.6 gal/hr	6% reduction.	Extraction of ethylene quench wastewater using isobutylene (S/W=0.101); RDC extractor used.	27

(continued)

TABLE C-1(continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII K-16	Phenol	L,C	I	69 ppm @ 4.6 gal/hr	4% reduction.	Extraction of ethylene quench wastewater using isobutane (S/W=0.097); RDC extractor used.	27
VII K-17	Phenol	L,C	I	579 ppm	72% reduction.	See VIIK-3 for comments.	27
VII K-18	Phenol	L,C	I	8800 ppm @ 3.21 gal/hr	97% reduction	See VIIK-5 for comments.	27
VII K-19	Phenol	L,C	I	8800 ppm @ 3.21 gal/hr	98% reduction.	See VIIK-7 for comments.	27
VII K-20	2,4,6-Trichlorophenol	R	U		Extractable w/benzene, alcohol and nitrobenzene.		90
VII K-21	Xylenols	L,C	I	227 ppm	96% reduction.	See VIIK-3 for comments.	27

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Phthalates (L)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
VII L-1	Bis (2-ethylhexyl) Phthalate	R	U		Extractable w/ethyl ether & benzene.		90
VII L-2	Butylbenzyl Phthalate	R	U		Extractable w/ethyl ether & benzene.		90
VII L-3	Di-N-Butyl Phthalate	R	U		Extractable w/ethyl ether & benzene.		90
VII L-4	Diethyl Phthalate	R	U		Extractable w/ethyl ether & benzene.		90
VII L-5	Dimethyl Phthalate	R	U		Extractable w/ethyl ether & benzene.		90
VII L-6	Di-N-Octyl Phthalate	R	U		Extractable w/ethyl ether & benzene.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Solvent Extraction (VII)
Chemical Classification: Polynuclear Aromatics (M)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
VII E-1	Anthracene	R	U		Extractable w/toluene.		90

(continued)

TABLE C-1CHEMICAL TREATABILITY

Concentration Process: Activated Carbon (IX)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX A-1	Allyl Alcohol	I	P	1000 ppm	21.9% reduction; final conc. of 789 ppm; capacity was 0.024 gm/gm of carbon. Adsorbability found to increase with molecular weight. For compounds of <4 carbons order of decreasing adsorption was: undissociated organic acids, aldehydes, esters, ketones, alcohols (when >4 carbons, alcohols moved ahead of esters), glycols. Aromatics had greatest adsorption. Results of two component isotherm tests could be predicted from single compound tests; however, in four-component tests, only about 60% of predicted adsorption occurred. Continuous columns produced 60-80% of theoretical isotherm capacity.	Carbon dose was 5g/l Westvaco Nuchar	35
IX A-2	n-Amyl Alcohol (1-Pentanol)	I	P	1000 ppm	71.8% reduction; 282 ppm final conc., 0.155 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-3	Butanol	B,L	P	100 ug/l	Complete removal. Desorption of alcohols from carbon by elutriating with various solvents ranged from 4 to 110%.	Filtrasorb 300 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, methyl	20

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX A-3	continued					chloride-acetone, and acetone.	
IX A-4	Butanol	I	P	1000 ppm	53.4% reduction; 466 ppm final conc., 0.107 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-5	Butanol	I	P	1000 ppm 500 ppm 100 ppm	75% reduction 67% reduction 78% reduction	24 hr. contact time; carbon dose was 10 times chemical conc.	72
IX A-6	t-Butanol	I	P	1000 ppm	29.5% reduction; 705 ppm final conc., 0.059 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-7	Cyclohexanol	B,L	P	100 μg/l	Complete removal.	See IXA-3 for additional results.	20
IX A-8	Decanol	B,L	P	100 μg/l	Complete removal.	See IXA-3 for additional results.	20
IX A-9	Ethanol	I	P	1000 ppm	10% reduction; 901 ppm final conc., 0.020 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-10	2-Ethyl-Butanol	I	P	1000 ppm	85.5% reduction; 145 ppm final conc., 0.170 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-11	2-Ethyl-Hexanol	I	P	700 ppm	98.5% reduction; 10 ppm final conc., 0.138 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-12	2-Ethyl-1-Hexanol	B,L	P	100 μg/l	Complete removal.	See IXA-3 for additional results.	20

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX A-13	m-Heptanol	B,L	P	100 μg/l	Complete removal.	See IXA-3 for additional results.	20
IX A-14	m-Hexanol	I	P	1000 ppm	95.5% reduction; 45 ppm final conc., 0.155 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-15	Isobutanol	I	P	1000 ppm	41.9% reduction; 581 ppm final conc., 0.084 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-16	Isopropanol	I	P	1000 ppm	12.6% reduction; 874 ppm final conc., 0.025 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-17	Methanol	I	P	1000 ppm	3.6% reduction; 964 ppm final conc., 0.007 gm/gm carbon capacity.	See IXA-1 for additional results.	35
IX A-18	Methanol	I	P	1000 ppm 200 ppm 15 ppm	17% reduction 33% reduction 33% reduction	24 hr. contact time; carbon dose was 10 times chemical conc.	72
IX A-19	Octanol	B,L	P	100 μg/l	Complete removal.	See IXA-3 for additional results.	20
IX A-20	Pentanol	B,L	P	100 μg/l	Complete removal.	See IXA-3 for additional results.	20
IX A-21	Propanol	B,L	P	100 μg/l	Complete removal.	See IXA-3 for additional results.	20
IX A-22	Propanol	I	P	1000 ppm	18.9% reduction; 811 ppm final conc., 0.038 gm/gm carbon capacity.	See IXA-1 for additional results.	35

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX B-1	Acetaldehyde	I	P	1000 ppm	11.9% reduction; 881 ppm final conc., 0.022 gm/gm carbon capacity. Adsorbability found to increase with molecular weight. For compounds of <4 carbons order of decreasing adsorption was: undissociated organic acids, aldehydes, esters, ketones, alcohols (when >4 carbons, alcohols moved ahead of esters), gylcols. Aromatics had greatest adsorption. Results of two-component isotherm tests could be predicted from single compound tests however, in four-component tests, only about 60% of predicted adsorption occurred. Continuous columns produced 60-80% of theoretical isotherm capacity.	Carbon dose was 5 g/l Westvaco Nuchar.	35
IX B-2	Acetic Acid	I	P	1000 ppm	24% reduction; 760 ppm final conc., 0.048 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-3	Acetone	I	P	1000 ppm	21.8% reduction; 782 ppm final conc., 0.043 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-4	Acetone Cyanohydrin	I	P	1000 ppm 200 ppm 100 ppm	60% reduction 45% reduction 30% reduction	24 hr. contact time; carbon dose was 10 times chemical conc.	72

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study: Study Type[c]	Description of Study: Waste Type[d]	Description of Study: Influent Char.	Results of Study	Comments	Ref.
IX B-5	Acrolein	I	P	1000 ppm	30.6% reduction; 694 ppm final conc., 0.061 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-6	Acrolein	R	U	1000 ppm	30% reduction at 0.5% carbon dose.		90
IX B-7	Acrylic Acid	I	P	1000 ppm	64.5% reduction; 355 ppm final conc., 0.129 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-8	Acrylonitrile	I	P	1000 ppm 100 ppm	51% reduction 28% reduction	24 hr. contact time; carbon dose was 10 times chemical conc.	72
IX B-9	Amyl Acetate (primary)	I	P	985 ppm	88% reduction; 119 ppm final conc., 0.175 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-10	Butyl Acetate	I	P	1000 ppm	84.6% reduction; 154 ppm final conc., 0.169 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-11	Butyl Acrylate	I	P	1000 ppm	95.9% reduction; 43 ppm final conc., 0.193 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-12	Butyraldehyde	I	P	1000 ppm	52.8% reduction; 472 ppm final conc., 0.106 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-13	Butyric Acid	I	P	1000 ppm	59.5% reduction; 405 ppm final conc., 0.119 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-14	Butyric Acid	B,L	P	100 ug/l	Complete reduction; No desorption from carbon by elutriating with solvent.	Filtrasorb 300 used. Solvents included pentane-acetone, diethyl ether,	20

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX B-14 cont						methylene chloride-acetone, methyl chloride-acetone, and acetone.	
IX B-15	Caproic Acid	B,L	P	100 ug/l	90% reduction; 3% desorbed from carbon by elutriating with solvent.	See IXB-14 for additional results	20
IX B-16	Caproic Acid	I	P	1000 ppm	97% reduction; 30 ppm final conc., 0.194 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-17	Crotonaldehyde	I	P	1000 ppm	45.6% reduction; 544 ppm final conc., 0.092 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-18	Cyclohexanone	I	P	1000 ppm	66.8% reduction; 332 ppm final conc., 0.134 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-19	Decanoic Acid	B,L	P	100 ug/l	Complete reduction; 2% desorbed from carbon by elutriating with solvent.	See IXB-14 for additional results.	20
IX B-20	Dicyclopentadiene (DCPC)	P,C	I	82 to 1000 ppb	Diisopropyl methylphosphonate (DIMP) and TOC used to measure performance. DCPC found to vaporize.	Contaminated groundwater. See IXB-23 for remarks.	86
IX B-21	Diethylene Glycol	I	P	1000 ppm	26.2% reduction; 738 ppm final conc., 0.053 gm/gm carbon capacity.	See IXB- 1 for additional results.	35
IX B-22	Diisobutyl Ketone	I	P	300 ppm	100% reduction; 0.060 gm/gm carbon capacity.	See IXB- 1 for additional results.	35

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX B-23	Diisoproply Methyl-phosphonate (DIMP)	P,C	I (Bog Water)	210 to 430 ppb DIMP; TOC about 40 ppm; pH 7.6 to 8.0	Average DIMP removal was 99.75% (<1.9 ppb in effluent)	Test 1- Influent flow 7 gpm; carbon feed rate 1649 µg/l, anionic polymer Herufloc 836.2 at 0.556 gm/l conc. and 1000 cc/min flow added; cationic polymer Cat-floc at 4 µg/l conc. and 26.5 cc/min flow added; duration of test 4 weeks; 28,600 gal. throughput.	86
			I (Bog Water)	290 to 470 ppb	Average DIMP removal was 98.77% (6.4 ppb in effluent)	Test 2- Carbon feed 1000 ug/l duration of test 3 weeks; other conditions similar to Test 1.	
					DIMP removal averaged 99% at 350 µg/l carbon dose and 96.33% at 250 ug/l carbon dose. Optimum anionic/cationic mixture was found to be anionic-0.13 gm/l and 120 cc/min, cationic - 1.59 gm/l & 25 cc/min.	Test 3- Influent flow rate 5 gpm; anionic conc. and flow-0.13 gm/l & 120 cc/min; cationic conc. and flow- 1.59 gm/l & 25 cc/min; carbon feed at 350 ug/l & 250 µg/l for 1 week each.	
					DIMP removal ranged from 92.5 to 97.5% at 175 µg/l carbon dose and 98.7% at 220 ug/l carbon dose.		

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study: Study Type[c]	Waste Type[d]	Influent Char.	Results of Study	Comments	Ref.
IX B-23 cont					DIMP removal steadily decreased to about 40% at carbon dose of 100 µg/l.		
			I (Bog Water)	400 ppb	DIMP conc. reduced to 50 ppb, reactivated carbon tested 17000 gal before breakthrough, virgin carbon treated 9600 gal; reactivated carbon capacity-3.8 ug DIMP/gm carbon (0.9 lb carbon/1000 gal); virgin carbon capacity 2.3 µg DIMP/gm carbon (1.4 lb carbon/1000 gal.)	Filtrasorb 300 carbon was used.	
			I (Ground Water)	2680 ppb	98% removal at carbon dose of 252 ug/l	Hydrodarco C carbon; duration of test-13100 gal.	
				2400 ppb	94 to 97% removal at carbon dose of 200 µg/l	Hydrodarco C carbon; duration of test - 9000 gal.	
				2564 ppb	Could not achieve steady state performance at carbon dose of 252 ug/l & flow rate of 225 gal/hr.	Aqua Nuchar carbon; duration of test - 15200 gal (2 weeks).	
IX B-24	Dipropylene Glycol	I	P	1000 ppm	16.5% reduction; 835 ppm final conc., 0.033 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-25	Dodecane	B,L	P	100 ug/l	Complete removal; 28% desorbed from carbon by elutriating with solvent.	See IXB-14 for additional results.	20

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX B-26	Ethyl Acetate	I	P	1000 ppm	50.5% reduction; 495 ppm final conc., 0.100 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-27	Ethyl Acrylate	I	P	1015 ppm	77.7% reduction; 226 ppm final conc., 0.157 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-28	Ethylene Glycol	I	P	1000 ppm	6.8% reduction; 932 ppm final conc., 0.014 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-29	Formaldehyde	I	P	1000 ppm	9.2% reduction; 908 ppm final conc., 0.018 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-30	Formic Acid	I	P	1000 ppm	23.5% reduction; 765 ppm final conc., 0.047 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-31	Heptanoic Acid	B,L	P	100 ug/l	10% reduction; 1% desorbed from carbon by elutriating with solvent.	See IXB-14 for additional results.	20
IX B-32	Hexadecane	B,L	P	100 ug/l	Complete reduction; 12% desorbed from carbon by elutriating with solvent.	See IXB- 14 for additional results.	20
IX B-33	Hexylene Glycol	I	P	1000 ppm	61.4% reduction; 386 ppm final conc., 0.122 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-34	Isobutyl Acetate	I	P	1000 ppm	82% reduction; 180 ppm final conc., 164 gm/gm carbon capacity.	See IXB-1 for additional results.	35

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX B-35	Isoprene	I	P	1000 ppm 500 ppm	86% reduction 86% reduction	See IXA-5	72
IX B-36	Isopropyl Acetate	I	P	1000 ppm	68.1% reduction; 319 ppm final conc., 0.137 gm/gm carbon capacity.	See IXB-1 for additional results	35
IX B-37	Lauric Acid	B,L	P	100 µg/1	Complete removal; No desorption from carbon by elutriation with solvent.	See IXB-14 for additional results.	20
IX B-38	Methyl Acetate	I	P	1030 ppm	26.2% reduction; 760 ppm final conc., 0.054 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-39	Methyl Butyl Ketone	I	P	988 ppm	80.7% reduction; 191 ppm final conc., 0.159 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-40	Methyl Decanoate	B,L	P	100 µg/1	Complete removal; 71% desorbed from carbon by elutriation with solvent.	See IXB-14 for additional results.	20
IX B-41	Methyl Dodecanoate	B,L	P	100 µg/1	Complete removal; 50% desorbed from carbon by elutriation with solvent.	See IXB-14 for additional results.	20
IX B-42	Methyl Ethyl Ketone	I	P	1000 ppm	46.8% reduction; 532 ppm final conc., 0.094 gm/gm carbon capacity.	See IXB- 1 for additional results.	35
IX B-43	Methyl Hexadecanoate	B,L	P	100 µg/1	Complete removal; 35% desorbed from carbon by elutriation with solvent.	See IXB- 14 for additional results.	20
IX B-44	Methyl Isoamyl Ketone	I	P	986 ppm	85.2% reduction; 146 ppm final conc., 0.169 gm/gm carbon capacity.	See IXB- 1 for additional results.	35

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX B-45	Methyl Octadecanoate	B,L	P	100 µg/l	Complete removal; 40% desorbed from carbon by elutriation with solvent.	See IXB-14 for additional results.	20
IX B-46	Methyl Propyl Ketone	I	P	1000 ppm	69.5% reduction; 305 ppm final conc., 0.139 gm/gm carbon capacity.	See IXB- 1 for additional results.	35
IX B-47	Myristic Acid	B,L	P	100 µg/l	Complete removal; no desorption from carbon by elutriation with solvent.	See IXB- 14 for additional results.	20
IX B-48	Octadecane	B,L	P	100 µg/l	Complete removal; no desorption from carbon by elutriation w/solvent.	See IXB- 14 for additional results.	20
IX B-49	Octanoic Acid	B,L	P	100 µg/l	50% removal; 1% desorbed from carbon by elutriation w/solvent.	See IXB- 14 for additional results.	20
IX B-50	Propional-dehyde	L	P	1000 ppm	27.7% reduction; 723 ppm final conc., 0.057 gm/gm carbon capacity.	See IXB- 1 for additional results.	35
IX B-51	Propionic Acid	B,L	P	100 µg/l	Complete removal, no desorption from carbon by elutriation with solvent.	See IXB- 1 for additional results.	20
IX B-52	Propionic Acid	I	P	1000 ppm	32.6% reduction; 674 ppm final conc., 0.065 gm/gm carbon capacity.	See IXB- 1 for additional results.	35
IX B-53	Propyl Acetate	I	P	1000 ppm	75.2% reduction; 248 ppm final conc., 0.149 gm/gm carbon capacity.	See IXB- 1 for additional results.	35
IX B-54	Propylene Glycol	I	P	1000 ppm	11.6% reduction; 884 ppm final conc., 0.024 gm/gm carbon capacity.	See IXB-1 for additional results.	35

(continued)

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX B-55	Propylene Oxide	I	P	1000 ppm	26.1% reduction; 739 ppm final conc., 0.052 gm/gm carbon capacity.	See IXB- 1 for additional results.	35
IX B-56	Pyruvic Acid	B,L	P	100 µg/l	Complete removal;no desorption from carbon using organic solvent.	See IXB-14 for additional results.	20
IX B-57	Tetradecane	B,L	P	100 µg/l	Complete removal; 25% desorbed from carbon by elutriation with solvent.	See IXB-14 for additional results.	20
IX B-58	Tetraethylene Glycol	I	P	1000 ppm	58.1% reduction; 419 ppm final conc., 0.116 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-59	Triethylene Glycol	I	P	1000 ppm	52.3% reduction; 477 ppm final conc., 0.105 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-60	Valeric Acid	B,L	P	100 µg/l	Complete removal; 10% desorbed from carbon by elutriation with solvent.	See IXB-14 for additional results.	20
IX B-61	Valeric Acid	I	P	1000 ppm	79.7% reduction; 203 ppm final conc., 0.159 gm/gm carbon capacity.	See IXB-1 for additional results.	35
IX B-62	Vinyl Acetate	I	P	1000 ppm	64.3% reduction; 357 ppm final conc., 0.129 gm/gm carbon capacity.	See IXB-1 for additional results.	35

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX C-1	Allyamine	I	P	1000 ppm	31.4% reduction; 686 ppm final conc., 0.063 gm/gm carbon capacity. Adsorbability found to increase with molecular weight. For compounds of <4 carbons order of decreasing adsorption was: undissociated organic acids, aldehydes, esters, ketones, alcohols (when >4 carbons, alcohols moved ahead of esters), glycols. Aromatics had greatest adsorption. Results of two component isotherm tests could be predicted from single compound tests; however, in four component tests only 60% of predicted adsorption occurred. Continuous columns produced 60-80% of theoretical isotherm capacity.	Carbon dose was 5 g/l Westvaco Nuchar.	35
IX C-2	Aniline	B,L	P	100 μg/l	100% reduction; No desorption from carbon by elutriation with solvents.	Filtrasorb 300 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, methyl chloride-acetone, and acetone.	20
IX C-3	Aniline	I	P	1000 ppm	74.9% removal; 251 ppm final conc.; 0.15 gm/gm carbon capacity.	See IXC-1 for additional results.	35

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX C-4	Butylamine	B,L	P	100 µg/1	100% removal; no desorption from carbon by elutriation with solvent.	See IXC-2 for additional results.	20
IX C-5	Butylamine	I	P	1000 ppm	52% reduction; 480 ppm final conc., 0.103 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-6	Cyclohexylamine	B,L	P	100 µg/1	100% removal; 38% desorption from carbon by elutriation with solvent.	See IXC-2 for additional results.	20
IX C-7	Dibutylamine	B,L	P	100 µg/1	100% removal; No desorption from carbon by elutriation with solvent.	See IXC-2 for additional results.	20
IX C-8	Di-N-Butylamine	I	P	1000 ppm	87% removal; 130 ppm final conc., 0.174 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-9	Diethanolamine	I	P	996 ppm	27.5% removal; 722 ppm final conc., 0.057 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-10	Diethylenetriamine	I	P	1000 ppm	29.4% removal; 706 ppm final conc., 0.062 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-11	Dihexylamine	B,L	P	100 µg/1	100% removal; 24% desorption from carbon by elutriation with solvent.	See IXC-2 for additional results.	20
IX C-12	Diisopropanolamine	I	P	1000 ppm	45.7% removal; 543 ppm final conc., 0.091 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-13	Dimethylamine	B,L	P	100 µg/1	100% removal; 82% desorption from carbon by elutriation with solvent.	See IXC-2 for additional results.	20

(continued)

TABLEC-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX C-14	Dimethyl-nitrosamine	I	P		Not adsorbed.		31
IX C-15	Di-N-Propylamine	I	P	1000 ppm	80.2% removal; 198 ppm final conc., 0.174 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-16	Ethylene-diamine	I	P	1000 ppm	10.7% removal; 893 ppm final conc., 0.021 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-17	N-Ethyl-morpholine	I	P	1000 ppm	47.3% removal; 527 ppm final conc., 0.095 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-18	Hexylamine	B,L	P	100 µg/l	100% removal; 24% desorbed from carbon by elutriation with solvent.	See IXC-2 for additional results.	20
IX C-19	2-Methyl-5-Ethylpyridine	I	P	1000 ppm	89.3% removal; 107 ppm final conc., 0.179 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-20	N-Methyl Morpholine	I	P	1000 ppm	42.5% removal; 575 ppm final conc., 0.085 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-21	Monoethan-olamine	I	P	1012 ppm	7.2% removal; 939 ppm final conc., 0.015 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-22	Monoisopro-panolamine	I	P	1000 ppm	20% removal; 800 ppm final conc., 0.04 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-23	Morpholine	B,L	P	100 µg/l	100% removal; 67% desorbed from carbon by elutriation with solvent.	See IXC-2 for additional results.	20

(continued)

TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX C-24	B-Napthylamine	I	P		Isotherm kinetics were as follows: Carbon — K — 1/n Darco — 77.4 — 0.361 Filtrasorb — 166.0 — 0.234 Carbon dose (mg/l) required to reduce 1 mg/l to 0.1 mg/l: Darco - 27 Filtrasorb - 10		31
IX C-25	Octylamine	B,L	P	100 µg/l	100% removal; no desorption from carbon by elutriation with solvent.	See IXC-2 for additional results.	20
IX C-26	Piperidine	B,L	P	100 µg/l	100% removal; 73% desorbed from carbon by elutriation with solvent.	See IXC-2 for additional results.	20
IX C-27	Pyridine	I	P	1000 ppm	53.3% removal; 467 ppm final conc., 0.107 gm/gm carbon capacity.	See IXC-1 for additional results.	35
IX C-28	Pyrrole	B,L	P	100 µg/l	100% removal; 16% desorbed from carbon by elutriation with solvent.	See IXC-2 for additional results.	20
IX C-29	Tributylamine	B,L	P	100 µg/l	100% removal; no desorption from carbon by elutriation with solvent.	See IXC-2 for additional results.	20
IX C-30	Triethanolamine	I	P	1000 ppm	33% removal; 670 ppm final conc., 0.067 gm/gm carbon capacity.	See IXC-1 for additional results.	35

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX D-1	Acetophenone	B,L	P	100 µg/l	50% reduction; 2% desorbed from carbon by elutriation with solvent.	Filtrasorb 300 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, methey chloride-acetone, and acetone.	20
IX D-2	Acetophenone	I	P	1000 ppm	97.2% removal; 28 ppm final conc., 0.194 gm/gm carbon capacity. Adsorbability found to increase with molecular weight. For compounds of <4 carbons order of decreasing adsorption was: undissociated organic acids, aldehydes, esters, ketones, alcohols (when >4 carbons, alcohols moved ahead of esters), glycols. Aromatics had greatest adsorption. Results of two component isotherm tests could be predicted from single compound tests; however, in four-component tests, only about 60% of predicted adsorption occurred. Continuous columns produced 60-80% of theoretical isotherm capacity.	Carbon dose was 5 g/l Westvaco Nuchar.	35

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX D-3	Benzaldehyde	B,L	P	100 µg/l	50% reduction; 2% desorbed from carbon by elutriation with solvent.	See IXD-1 for additional results.	20
IX D-4	Benzaldehyde	I	P	1000 ppm	94% reduction; 60 ppm final conc., 0.188 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-5	Benzaldehyde	I	P	1000 ppm 500 ppm 100 ppm	99% removal 99% removal 98% removal	24 hr. contact time; carbon dose was 10 times chemical conc.	72
IX D-6	Benzene	P,C	H	1 ppb	90% removal (to 0.1 ppb effluent conc.) achieved in 8.5 min. contact time.	Spilled material treated using EPA's mobile treatment trailer.	6
IX D-7	Benzene	I	P	1 ppm	0.7 mg/gm carbon capacity.		21
IX D-8	Benzene	I	P		Isotherm kinetics were as follows: Carbon — K — 1/n Darco — 26.8 — 1.305 Filtrasorb — 18.5 — 1.158 Carbon dose (mg/l) required to reduce 1 mg/l to 0.1 mg/l: Darco - 678 Filtrasorb - 705		31
IX D-9	Benzene	I	P	416 ppm	95% reduction; 21 ppm final conc., 0.080 gm/gm carbon capacity.	See IXD- 2 for additional results.	35

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX D-10	Benzene	R	I	1500 ppm TOC	Effluent conc. of 30 ppm TOC achieved (98% removal)	At contact time of 55 min.; 0.15 MGD flow; pretreatment included pH adjustment.	38
IX D-11	Benzene	I	P	500 ppm 250 ppm 50 ppm	95% removal 91% removal 60% removal	24 hr. contact time; carbon dose was 10 times chemical conc.	72
IX D-12	Benzene	R	U	416 ppm	95% removal at 0.5% carbon dose.		90
IX D-13	Benzidine	I	P		Isotherm kinetics were as as follows: Carbon — K — 1/n Darco — 85.4 — 0.253 Filtrasorb — 173 — 0.288 Carbon dose (mg/l) required to reduce 1 mg/l to 0.1 mg/l: Darco - 19 Filtrasorb - 10		31
IX D-14	Benzil	B,L	P	100 ug/l	50% removal; 8% desorbed from carbon by elutriation with solvent.	See IXD-1 for additional results.	20
IX D-15	Benzoic Acid	B,L	P	100 ug/l	Complete removal; 2% desorbed from carbon by elutriation with solvent.	See IXD-1 for additional results.	20
IX D-16	Benzoic Acid	I	P	1000 ppm	91.1% removal; 89 ppm final conc., 0.183 gm/gm carbon capacity.	See IXD-2 for additional results.	35

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX D-17	Chlorinated Aromatics	R	I	6000 ppm TOC	Effluent conc. of 3000 ppm TOC achieved (50% reduction). High effluent conc. because activated carbon served as pretreatment before biological system.	At contact time of 1375 min; flow of 6000 gpd; pretreatment included chemical reduction.	38
IX D-18	Chlorobenzene	I	P	1 mg/l	93 mg/gm carbon capacity.		21
IX D-19	Chlorobenzene	F,C	D		50% reduction.	Treatment of effluent from 0.66 m^3/sec biological system.	64
IX D-20	Chlorobenzene	R	U	416 ppm	95% removal at 0.5% carbon dose.		90
IX D-21	1-Chloro-2-Nitrobenzene	I	P	1 ppm	103 mg/gm adsorption capacity.		21
IX D-22	Cumene	B,L	P	100 µg/l	Complete removal; 8% desorbed from carbon by elutriation with solvent.	See IXD-1 for additional results.	20
IX D-23	o-Dichlorobenzene	B,L	P	100 µg/l	Complete removal; 5% desorbed from carbon by elutriation with solvent.	See IXD-1 for additonal results.	20
IX D-24	o-Dichlorobenzene	R	U	416 ppm	95% removal at 0.5% carbon dose.		90

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX D-25	m-Dichlorobenzene	B,L	P	100 µg/l	Complete removal; 15% desorbed from carbon by elutriation with solvent.	See IXD-1 for additional results.	20
IX D-26	m-Dichlorobenzene	R	U	416 ppm	95% removal at 0.5% carbon dose.		90
IX D-27	1,4-Dichlorobenzene	F,C	D		60% removal	Treatment of effluent from 0.66 m^3/sec biological system.	64
IX D-28	p-Dichlorobenzene	B,L	P	100 µg/l	100% removal; 2% desorbed from carbon by elutriation with solvent.	See IXD-1 for additional results.	20
IX D-29	p-Dichlorobenzene	R	U	416 ppm	95% removal at 0.5% carbon dose.		90
IX D-30	3,3′-Dichlorobenzidine	I	P		Isotherm kinetics were as follows: Carbon — K — 1/n Darco — 126 — 0.253 Filtrasorb — 240 — 0.194 Carbon dose (mg/l) to reduce 1 mg/l to 0.1 mg/l: Darco - 12.8 Filtrasorb - 5.7		31
IX D-31	Dimethylaniline (Xylidine)	P,C	H	380 ppb	94% removal (23 ppb in effluent) achieved in 85 min. contact time.	250,000 gal. spilled materials treated with EPA mobile treatment trailer.	6

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX D-32	2,4-Dinitrotoluene	R	U	416 ppm	95% removal at 0.5% carbon dose.	Not thermally regenerable.	90
IX D-33	2,6-Dinitrotoluene	R	U	416 ppm	95% removal at 0.5% carbon dose.	Not thermally regenerable.	90
IX D-34	Ethylbenzene	I	P	1 mg/l	53 mg/gm carbon capacity.		21
IX D-35	Ethylbenzene	I	L	115 ppm	84.3% reduction; 21 ppm final conc., 0.08 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-36	Ethylbenzene	F,C	D		50% removal	Treatment of effluent from 0.66 m^3/sec biological system.	64
IX D-37	Ethylbenzene	R	U	115 ppm	84.3% removal at 0.5% carbon dose.		90
IX D-38	Hexachlorobenzene	R	U	416 ppm	95% removal at 0.5% carbon dose.		90
IX D-39	Hydroquinone	I	P	1000 ppm	83.3% removal; 167 ppm final conc., 0.167 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-40	Isophrone	I	P	1000 ppm	96.6% removal; 34 ppm final conc., 0.193 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-41	Isophrone	R	U	1000 ppm	96.6% removal at 0.5% carbon dose.		90

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX D-42	4,4'-Methylene Bis-(2-Chloro-aniline	I	P		Isotherm kinetics were as follows: Carbon — K — 1/n Darco — 120 — 0.96 Filtrasorb — 240 — 0.982 Carbon dose (mg/l) to reduce 1 mg/l to 0.1 mg/l: Darco - 27 Filtrasorb - 15		31
IX D-43	Nitrobenzene	I	P	1 ppm	68 mg/gm adsorption capacity		21
IX D-44	Nitrobenzene	I	P	1023 ppm	95.6% removal; 44 ppm final conc., 0.196 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-45	Nitrobenzene	R	U	416 ppm	95% removal at 0.5% carbon dose.		90
IX D-46	Paraldehyde	I	P	1000 ppm	73.9% removal; 261 ppm final conc., 0.148 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-47	Pyridine	I	P	1000 ppm	47.3% removal; 527 ppm final conc., 0.095 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-48	Pyridine	I	P	1000 ppm 500 ppm	86% removal; 145 ppm final conc., 86% removal; 71 ppm final conc.	24 hr. contact time; carbon dose was 10 times chemical conc.	72
IX D-49	Styrene	I	P	1 ppm	120 mg/gm adsorption capacity.		21

(continued)

TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX D-50	Styrene	I	P	180 ppm	88.8% removal; 44 ppm final conc., 0.196 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-51	Styrene	I	P	200 ppm 100 ppm 20 ppm	97% removal 93% removal 55% removal	24 hr contact time; carbon dose was 10 times chemical conc.	72
IX D-52	Styrene Oxide	I	P	1000 ppm	95.3% removal; 47 ppm final con., 0.19 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-53	Toluene	P,C	H	120 ppb	99.8% removal (0.3 ppb in effluent achieved in 8.5 min contact time.	250,000 gal spilled materials treated with EPA mobile treatment trailer.	6
IX D-54	Toluene	I	P	317 ppm	79.2% removal; 66 ppm final conc., 0.05 gm/gm carbon capacity.	See IXD-2 for additional results.	35
IX D-55	Toluene	R	U	317 ppm	79% removal at 0.5% carbon dose.		90
IX D-56	Toxaphene	I	I	155 ppb pH 7.0	>99% removal; <1 ppb final conc., 42 mg/gm carbon capacity.		66
IX D-57	1,2,4-Trichlorobenzene	B,L	P	100 μg/l	100% removal; no desorption from carbon by elutriation with solvent.	See IXD-1 for additional results.	20
IX D-58	1,2,4-Trichlorobenzene	F,C	D		70% reduction.	Treatment of effluent from 0.66 m^3/sec biological system.	64
IX D-59	1,2,4-Trichlorobenzene	R	U	416 ppm	95% removal at 0.5% carbon dose.		90

(continued)

TABLEC-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX D-60	2,4,6-Trinitrotoluene (TNT)	P,C	I	108 ppm	Carbon adsorption capacity was 0.125 gm/gm at 1 ppm breakthrough after 600 bed volume (B.V.)	Filtrasorb 300 used. Thermal regeneration not possible because of explosion potential.	2
IX D-61	2,4,6-Trinitrotoluene (TNT) and other munitions plant wastewaters: Cyclonite(RDX), Nitramine (Tetryl), and cyclotetramethylene tetranitramine (HMX).	R	I	Not reported	Adsorption capacities (Lb/Lb carbon): Contaminant / Breakthrough / Saturation TNT 0.098 0.125 RDX 0.300 0.550 RDX & 0.008 0.048 TETRYL 0.002 0.024 TNT & 0.125 0.181 RDX 0.074 0.090 TNT & 0.134 HMX 0.006 (Note: breakthrough conc. not defined.) Typical conc. of contaminants in wastewaters: TNT - 0-400 ppm RDX - 50-100 ppm pH - 3.5-7.0 Flow - 0.02-1.0 MGD Temp - 60-160°F	TNT is preferentially adsorbed over RDX; when RDX $\geq$ TNT conc. TNT capacity reduced 50%. For 80 gpm facility costs estimated to be $8.90/1000 gal.	40
IX D-62	Xylene	P,C	H	140 ppb	> 99.9% removal (0.1 ppb in effluent) achieved in 8.5 min. contact time.	250,000 gal. spilled materials treated with EPA mobile treatment trailer.	6

(continued)

TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX D-63	Xylene	I	P	200 ppm 100 ppm	86% removal 68% removal	24 hr. contact time; carbon dose was 10 times chemical conc.	72

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Ethers (E)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX E-1	Bis(2-chloroisopropyl) Ether	R	U	Not reported	100% removal at 0.5% carbon dose.		90
IX E-2	Bis(chloroethyl) Ether	R	U	94 ppb	50% removal		90
IX E-3	Butyl Ether	I	P	197 ppm	100% removal; 0.039gm/gm carbon capacity. Adsorbality found to increase with molecular weight. For compounds of <4 carbons, order of decreasing adsorption was: undissociated organic acids, aldehydes, esters, ketones, alcohols (when>4 carbons, alcohols moved ahead of esters), glycols. Aromatics had greatest adsorption. Results of two-component isotherm tests could be predicted from single compound tests; however, in four-component tests, only about 60% of predicted adsorption occurred. Continuous columns produced 60-80% of theoretical isotherm capacity.	Carbon dose was 5g/l Westvaco Nuchar.	35

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Ethers (E)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX E-4	Dichloroisopropyl Ether	I	P	1008 ppm	100% removal; 0.20 gm/gm carbon capacity.	See IXE-3 for additional results.	35
IX E-5	Diethylene Glycol Monobutyl Ether	I	P	1000 ppm	82.7% removal; 173 ppm final conc., 0.166 gm/gm carbon capacity.	See IXE-3 for additional results.	35
IX E-6	Diethylene Glycol Monoethyl Ether	I	P	1010 ppm	43.6% removal; 570 ppm final conc., 0.087 gm/gm carbon capacity.	See IXE-3 for additional results.	35
IX E-7	Ethoxytriglycol	I	P	1000 ppm	69.7% removal; 303 ppm final conc., 0.139 gm/gm carbon capacity.	See IXE-3 for additional results.	35
IX E-8	Ethylene Glycol Monobutyl Ether	I	P	1000 ppm	55.9% removal; 441 ppm final conc., 0.112 gm/gm carbon capacity.	See IXE-3 for additional results.	35
IX E-9	Ethylene Glycol Monoethyl Ether	I	P	1022 ppm	31% removal; 705 ppm final conc., 0.063 gm/gm carbon capacity.	See IXE-3 for additional results.	35
IX E-10	Ethylene Glycol Monoethyl Ether Acetate	I	P	1000 ppm	65.8% removal; 324 ppm final conc., 0.132 gm/gm carbon capacity.	See IXE- for additional results.	35
IX E-11	Ethylene Glycol Monohexyl Ether	I	P	975 ppm	87.1% removal; 126 ppm final conc., 0.170 gm/gm carbon capacity.	See IXE-3 for additional results.	35
IX E-12	Ethylene Glycol Monomethyl Ether	I	P	1024 ppm	13.5% removal; 886 ppm final conc., 0.028 gm/gm carbon capacity.	See IXE-3 for additional results.	35
IX E-13	Isopropyl Ether	I	P	1023 ppm	80% removal; 203 ppm final conc., 0.162 gm/gm carbon capacity.	See IXE-3 for additional results.	35

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX F-1	Bromochloromethane	I	P S S,M	Not reported	Sorptive capacity x/m at residual conc (C_f) of 100 ppb was 3.37 mg/g in pure compound studies, 2.56 in a mixture and 0.875 in secondary effluent.	Mixture of 6 halocarbons added to secondary effluent.	21
IX F-2	Bromodichloromethane	R	U		Reported to be adsorbed		90
IX F-3	Bromoform	L	W	0.2ppb		See IXF-44 for results.	46
IX F-4	Bromoform	B,L	P	100 ppb	100% removal; 10% desorbed from carbon by elutriation with solvent	Filtrasorb 300 used Solvent included pentane-acetone, diethylether, methylene chloride-acetone, methyl chloride-acetone, and acetone.	20
IX F-5	Bromomethane	R	U		Reported to be adsorbed.		90
IX F-6	Carbon Tetrachloride	P,C	H	1.1 ppb	Not detected in effluent after 8.5 min contact time.	250,000 gal spilled materials treated with EPA mobile treatment trailer.	6
IX F-7	Carbon Tetrachloride	I	P	Not reported	Sorptive capacity (x/m) at residual conc. (C_f) of 100 ppb was 4.66 mg/g		21

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Halocarbons (F)

No.^{a}	Chemical^{b}	Description of Study Study Type^{c}	 Waste Type^{d}	 Influent Char.	Results of Study	Comments	Ref.
IX F-8	Carbon Tetrachloride	R	U		Reported to be adsorbed.		90
IX F-9	Chloroethane	R	U		Reported to be adsorbed.		90
IX F-10	Chloroethylene	R	U		Reported to be adsorbed.		90
IX F-11	Chloroform	I	P S S,M	Not reported	Sorptive capacity (x/m) at residual conc. (C_f) of 100 ppb was 1.58 mg/g in pure compound studies, 0.93 in a mixture, and 0.365 in secondary effluent.	Mixture of 6 halocarbons added to sedondary effluent.	21
IX F-12	Chloroform	L	W		At 2 ppm chloroform, equilibrium capacity was 12 mg/g.	See IXF-44 for results.	46
IX F-13	Dibromochloromethane	L	W	3.9 ppb		See IXF-44 for results.	46
IX F-14	Dibromochloromethane	I	P S S,M	Not reported	Sorptive capacity (x/m) at residual conc. (C_f) of 100 ppb was 7.52 mg/g in pure compound studies, 4.54 in a mixture, and 0.885 in secondary effluent.	Mixture of 6 halocarbons added to secondary effluent.	21

(continued)

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Halocarbons(F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX F-15	Dibromochloromethane	R	U		Reported to be adsorbed.		90
IX F-16	Dichloroethane	P,C	H	12 ppb	Not detected in effluent after 8.5 min contact time.	250,000 gal spilled materials treated with EPA mobile treatment trailer.	6
IX F-17	Dichloroethane	I	P S S,M	Not reported	Sorptive capacity (x/m) at residual conc.(C_f) of 100 ppb was 1.07 mg/g in pure compound studies, 0.44 in a mixture, and 0.52 in secondary effluent.	Mixture of 6 halocarbons added to secondary effluent.	21
IX F-18	1,1-Dichloroethane	L	W	2.3 ppb		See IXF-44 for results.	46
IX F-19	1,1-Dichloroethane	R	U		Reported to be adsorbed.		90
IX F-20	1,2-Dichloroethane	L	W	2.1 ppb		See IXF-44 for results.	46
IX F-21	1,2-Dichloroethane	R	U	1000ppm	81.1% removal at 0.5% carbon dose.		90
IX F-22	1,1-Dichloroethylene	R	U		Reported to be adsorbed.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX F-23	1,2-Dichloroethylene	L	W	0.2 ppb		See IXF-44 for results.	46
IX F-24	1,2-trans-Dichloroethylene	R	U		Reported to be adsorbed.		90
IX F-25	Dichlorofluoromethane	R	U		Reported to be adsorbed.		90
IX F-26	Chlorinated Hydrocarbons	R	U	4 ppm TOC at 1 MGD	Effluent conc. of 0.05 ppm TOC achievable at contact time of 8 min.	Flow equalization used as pretreatment.	38
IX F-27	Dichloromethane	R	U		Reported to be adsorbed.		90
IX F-28	1,2-Dichloropropane	R	U	1000 ppm	92.9% removal at 0.5% carbon dose.		90
IX F-29	1,2-Dichloropropylene	R	U		Reported to be adsorbed.		90
IX F-30	Ethylene Dichloride (EDC)	I	L	1000 ppm	81.1% reduction, 189 ppm final conc., 0.163 g/g carbon capacity. Adsorbability found to increase with molecular weight. For compounds of <4 carbons, order of decreasing adsorption was: undissociated organic acids, aldehydes, esters, ketones, alcohols (when	Carbon dose was 5 g/l Westvaco Nuchar.	35

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Halocarbons(F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX F-30 cont					>4 carbons, alcohols moved ahead of esters), glycols. Aromatics had greatest adsorption. Results of two-component isotherm tests could be predicted from single compound tests; however, in four-component tests, only about 60% of predicted adsorption occurred. Continuous columns produced 60-80% of theoretical isotherm capacity.		
IX F-31	Ethylene Dichloride (EDC)	I	I	Industrial wastewaters containing numerous halocarbons with predominately EDC at up to 9000ppm	Carbon adsorption capacity to achieve 10 ppm EDC residual ranged from 0.47 to 1.25 gm EDC/gm carbon. Capacity to achieve 0.1 ppm EDC residual ranged from 0.0145 to 0.13 gm EDC/gm carbon. To obtain 0.5 ppm TOC residual, capacity ranged from 0.052 to 0.7 gm TOC/gm carbon. Capacity to achieve 50 ppm TOC residual ranged from 7.0 to 150 gm TOC/gm carbon.	Calgon (Filtrasorb 400), Westvaco(WVG) WITCO, and Barneby-Cheney (BCNB-9377) carbons were used. Capacity was dependent on wastewater being tested and the carbon.	95

(continued)

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Halocarbons(F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX F-32	Ethylene Dichloride (EDC)	L,C (3 columns in series 20 mm ID by 450mm length	I	Industrial wastewaters containing numerous halocarbons with predominately EDC. TC 1200ppm EDC-6400 to 6800ppm pH->11 total chlorinated hydrocarbons -8000ppm	EDC did not breakthrough (to original concentration) at up to 57 BV; however, reduction dropped below 90% after between 10 and 28 BV as flow increased from ∿0.85 to 2.40 L/sq m. Westvaco WVG performed slightly better than Calgon Filtrasorb 400. Minimum level of effluent TC attainable was 300 ppm.	100 g of loaded carbon was regenerated with 1 atm of steam for 5 min; after 5 regenerations carbon capacity was 0.186 gm EDC/gm carbon or 93% of fresh carbon.	95
IX F-33	Hexachlorobutadiene	B,L	P	100 ppb	100% removal; 31% desorbed from carbon by elutriation with solvent	See IXF-4 for additional comments.	20
IX F-34	Hexachloroethane	B,L	P	100 ppb	100% removal; 98% desorbed from carbon by elutriation with solvent	See IXF-4 for additional comments.	20

(continued)

TABLE C-1 (continued)

Concentration Process: Activated Carbon
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX F-35	Hexachloroethane	R	U		Reported to be adsorbed.		90
IX F-36	Methylene Chloride	P,C	H	190 ppb	73% removal with 51 ppb detected in effluent after 8.5 min contact time.	250,000 gal spilled materials treated with EPA mobile treatment trailer.	6
IX F-37	Propylene Dichloride	I	L	1000 ppm	92.9% reduction, 71 ppm final conc., 0.183 g/g carbon capacity.	See IXF-32 for additional results.	35
IX F-38	Tetrachloroethane	B,L	P	100 ppb	100% removal; 70% desorbed from carbon by elutriation with solvent.	See IXF-4 for additional comments	20
IX F-39	1,1,2,2-Tetrachloroethane	R	U		Reported to be adsorbed.		90
IX F-40	Tetrachloroethylene	L	W	179 ppb		See IXF-44 for results.	46
IX F-41	Tetrachloroethylene	R	U		Reported to be adsorbed.		90
IX F-42	Tribromomethane	R	U		Reported to be adsorbed.		90

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Halocarbons(F)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX F-43	Tribromomethane	I	P S S,M	Not reported	Sorptive capacity(x/m) at residual conc. (C_f) of 100 ppb was 28.7 mg/g in pure compound studies, 10.8 in a mixture, and 1.53 in secondary effluent.	Mixture of 6 halocarbons added to secondary effluent.	21
IX F-44	1,1,1-Trichloroethane	L	W	551 ppb	Performance for treatment of water containing several halogens. Virgin / Regenerated BV to 33ppb compound leakage: 5100 / 4000 Days: 13.3 / 10.4 Gal treated/cu ft sorbent: 38,250 / 30.000	Column studies 14mm dia glass tubes, height 4" (15 cu cm adsorbent) Flow-2 gpm/cu ft (16 BV/hr) Regenerated at 37 lb steam/cu ft @5 psig	46
IX F-45	1,1,1-Trichloroethane	R	U		Reported to be adsorbed.		90
IX F-46	1,1,2-Tri chloroethane	R	U		Reported to be adsorbed.		90

(continued)

TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Halocarbons(F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX F-47	Trichloroethylene (TCE)	P,C	H	21 ppb	98.6% removal with 0.3 ppb detected in effluent after 8.5 min contact time.	250,000 gal spilled materials treated with EPA mobile treatment trailer.	6
IX F-48	Trichloroethylene	R	U		Reported to be adsorbed.		90
IX F-49	Trichlorofluoromethane	R	U		Reported to be adsorbed.		90
IX F-50	1,2,3-Trichloropropane	B,L	P	100 ppb	100% reduction; 35% desorbed from carbon by elutriation with solvent	See IXF-4 for additional comments.	20

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX G-1	Arsenic	F,C	M	1.1 ppb 1.8 ppb	No reduction. Increase to 2.4 ppb.	Carbon used as advanced treatment of biologically & chemically treated waste water. Plant capacity 0.66 cu m/sec. Data presented for two time periods.	64
IX G-2	Barium	F,C	M	32 ppb 31 ppb	No reduction. No reduction.	See IXG-1 for comments.	64
IX G-3	Cadmium	F,C	M	2.5 ppb 1.8 ppb	12% reduction; 2.2 ppb effluent conc. 6% reduction; 1.7 ppb effluent conc.	See IXG-1 for comments.	64
IX G-4	Cadmium	P,C	R	0.029 ppm	With virgin Filtrasorb 200 average removal was 19%; w/exhausted FS 200 average removal was 37%.	Study consisted of 8 tests of about 100 hr duration each.	82
IX G-5	Chromium	F,C	M	84.0ppb	43% reduction; 48.0 ppb effluent conc.	See IXG-1 for comments.	64
IX G-6	Chromium	F,C	M	41.0ppb	37% reduction; 26.0 ppb effluent conc.	See IXG-1 for comments.	64
IX G-7	Chromium^{+3}	L,I	P	100 ppm	Carbon dose (ppm) — % Removal 0 — 0 500 — 5 1,000 — 7.5	Test chemical used was $CrCl_3$ with 24 hr carbon contact time.	72

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX G-7 cont					Carbon dose (ppm) — % Removal 5,000 — 17.5 10,000 — 47.5		
IX G-8	Chromium^{+6}	L,I	P	100 ppm	Carbon dose (ppm) — % Removal 0 — 0 500 — 16 1,000 — 26 5,000 — 34 10,000 — 36	24 hr contact time, test chemical was $K_2Cr_2O_7$	72
IX G-9	Copper	F,C	M	88 ppb	69% reduction; 27 ppb effluent conc.	See IXG-1 for comments.	64
IX G-10	Copper	F,C	M	49 ppb	35% reduction; 32 ppb effluent conc.	See IXG-1 for comments.	64
IX G-11	Copper	L,I	P	100 ppm	Carbon Dose (ppm) — % Removal 0 — 0 500 — 8 1,000 — 10 5,000 — 73 10,000 — 96.4	24 hr contact time, test chemical was Cu SO_4	72
IX G-12	Iron	F,C	M	207 ppb	68% reduction; 66 ppb effluent conc.	See IXG-1 for comments.	64
IX G-13	Iron	F,C	M	40 ppb	Conc. increased to 45 ppb in effluent.	See IXG-1 for comments.	64

(continued)

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX G-14	Lead	F,C	M	22 ppb	Conc. increased to 26 ppb	See IXG-1 for comments.	64
IX G-15	Lead	F,C	M	4.7 ppb	Conc. increased to 5.3 ppb.	See IXG-1 for comments.	64
IX G-16	Lead	L,I	P	100 ppm	Carbon dose (ppm) — % Removal 0 — 0 500 — 13 1,000 — 17.7 5,000 — 84.0 10,000 — 93.0	24 hr contact time, test chemical used $Pb(NO_3)_2$	72
IX G-17	Manganese	F,C	M	6.2 ppb	21% reduction; 4.9 ppb effluent conc.	See IXG-1 for comments.	64
IX G-18	Manganese	F,C	M	2.3 ppb	Conc. increased to 4.1 ppb.	See IXG-1 for comments.	64
IX G-19	Manganese	L,I	P	100 ppb	Carbon dose (ppm) — % Removal 0 — 0 500 — 1 1,000 — 3 5,000 — 25 10,000 — 50	24 hr contact time, test chemical used was $MnCl_2$.	72
IX G-20	Mercury	F,C	M	3.6 ppb	Conc. increased to 6.7 ppb.	See IXG-1 for comments.	64

(continued)

TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX G-21	Mercury	F,C	M	1.2 ppb	Conc. increased to 4.9 ppb.	See IXG-1 for comments.	64
IX G-22	Mercury	L,I	P	100 ppm	Carbon Dose (ppm) — % Removal 0 — 0 500 — 99 1,000 — 99 5,000 — 99 10,000 — 99	24 hr contact time, test chemical used was Hg Cl_2.	72
IX G-23	Mercury	U	U	10 ppb	80% reduction achieved with carbon dose of 100 Mg/l. PAC + chelating agent.	Efficiency of reduction was dependent on pH. Optimum pH was 7.0. Tannic Acid and Citric Acid were ineffective as chelating agents.	87
IX G-24	Mercury	R	U		80% reduction by PAC & Alum Coagulation.	GAC reduction of Hg enhanced by use of chelating agent.	90
IX G-25	Nickel	L,I	P	100 ppm	Carbon dose (ppm) — % Removal 0 — 0 500 — 4 1,000 — 5 5,000 — 10.5 10,000 — 52	24 hr contact time, test chemical used was $NiCl_2$.	72
IX G-26	Selenium	R	U	500 ppm	GAC treatment after Lime ppt. yielded 96% reduction.		90

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX G-27	Thallium	R	U		GAC treatment after Lime ppt. yielded 84% reduction.		90
IX G-28	Zinc	F,C	M	670 ppb	81% reduction; 124 ppb effluent conc.	See IXG-1 for comments.	64
IX G-29	Zinc	F,C	M	412 ppb	61% reduction; 162 ppb effluent conc.	See IXG-1 for comments.	64

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Polychlorinated Biphenyls (I)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX I-1	PCB's (Unspecified)	C,P	H	19 ppb	Not detectable in effluent with 60 min contact time.	Treatment by EPA trailer.	6
IX I-2	PCB's (Unspecified)	C,P	H	400 ppb @ 0.6 MG treated	Not detectable in effluent with 30-40 min contact time.	See IXI-1 for comments.	6
IX I-3	PCB's (Unspecified)	C,P	H	1.0 ppb @ 12 MG treated	Not detectable in effluent with 8.5 min contact time.	See IXI-1 for comments.	6
IX I-4	Arochlor 1242	L,B,I	P	45 ppb	<0.5 ppb final conc. carbon capacity was 25 mg/g.	Pulverized FS-300	8
IX I-5	Arochlor 1242	I	P	45 ppb	4.3 mg/g capacity for a 1.1 ppb final conc.		22
IX I-6	Arochlor 1242	I	S	45 ppb	25 mg/g capacity for a <0.5 ppb final conc.		38
IX I-7	Arochlor 1242	I	I	45 ppb	25 mg/g capacity for a <0.5 ppb final conc.		66
IX I-8	Arochlor 1254	L,B,I	P	49 ppb	72 mg/g of carbon capacity for a final conc. of <0.5 ppb	Pulverized FS-300 used.	8
IX I-9	Arochlor 1254	I	P	160 ppb	15.75 mg/g capacity for 98.5% reduction.		22
IX I-10	Arochlor 1254	I	P	11.15ppb and 37.5 ppb	0.37 mg/g capacity for 99% reduction.		22

(continued)

TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Polychlorinated Biphenyls (I)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IXI-11	Arochlor 1254	C,L	P	0.25 ppb at 100ml per hr	<0.05 ppb final conc. for 240 BV.	Experiment lasted 5 days.	22
IXI-12	Arochlor 1254	F,C	P	50 ppb	<1.0 ppb final effluent at 0.006 lb/lb capacity.	Cost estimate for full scale columns are $0.65/100 gal at 0.25 Mgd.	22
IXI-13	Arochlor 1254	I	P	49 ppb	1.0 mg/g capacity for 1.2 ppb effluent.		22
IXI-14	Arochlor 1254	I	S	49 ppb pH=7.0	7.2 mg/g capacity for final conc. of 0.5 ppb.		38
IXI-15	Arochlor 1254	I	I	49 ppb	See IXI-13 results		66
IXI-16	Arochlor 1254	B,L	P	100 ppb	94.4% average reduction; 14% desorbed from carbon by elutriation w/solvent	FS-300 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, chloroform-acetone, acetone.	20

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX J-1	Aldrin	B,L	P	100 ppb	100% reduction; 2% desorbed by elutriation with solvent.	Calgon FS-300 used.	20
IX J-2	Aldrin	I	S	48 ppb	30 mg/g of carbon capacity for a final conc. of <1.0 ppb.	pH = 7.0	38
IX J-3	Aldrin	L,B,I	P	48 ppb	30 mg/g of carbon capacity for a final conc. of <1.0 ppb.	Pulverized FS-300	8
IX J-4	Aldrin	C,P	H	8.5 ppb @ 0.1 MG treated	98% reduction w/17 min contact time.	Treated by EPA mobile trailer.	6
IX J-5	Aldrin	C,P	H	60.5 ppb @ 3000 gal treated.	99.8% reduction w/240 min contact time.	See IXJ-4 for comments.	6
IX J-6	2,4-D butyl ester	L,B	P	100 ppb	100% reduction; 10% desorbed from carbon by elutriation w/solvent.	Calgon FS-300 used.	20
IX J-7	Chlordane	C,P	H	13 ppb @ 1.0 MG treated	97.3 reduction; w/17 min contact time.	See IXJ-4 for comments.	6
IX J-8	Chlordane	C,P	H	1430 ppb @ 3000 gal treated	99.99% reduction; w/240 min contact time.	See IXJ-4 for comments.	6
IX J-9	DDD	I	S	56 ppb pH = 7.0	130 mg/g carbon capacity for a final conc. of 0.1 ppb.		38
IX J-10	DDD	I	P	56 ppb	See IXJ-9 results.	Pulverized FS-300 used.	8

(continued)

TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX J-11	DDD	I	I	56 ppb pH=7.0	See IXJ-9 results.		66
IX J-12	DDE	I	I	38 ppb ph=7.0	9.4 mg/g carbon capacity for a final conc. of <1.0 ppb.		66
IX J-13	DDE	I	P	38 ppb	See IXJ-12 results.	Pulverized FS-300 used.	8
IX J-14	DDE	I	S	38 ppb pH=7.0	See IXJ-12 results.		38
IX J-15	DDT	I	S	41 ppb pH=7	11 mg/g of carbon capacity for a final conc. of 0.1 ppb		38
IX J-16	DDT	L,B,I	P	41 ppb	11 mg/g of carbon capacity for a final conc. of 0.15 ppb.	Pulverized FS-300	8
IX J-17	DDT	C,L,R	P,R	10 ppb	Greater than 99% reduction achieved.	Cumulative removal following prechlorination and coagulation-filtration	6
IX J-18	DDT	B,L	P	100 ppb	100% reduction; 51% desorbed from carbon by elutriation w/solvent.	Calgon FS-300	20
IX J-19	DDT	I	I	41 ppb pH=7	See IXJ-15 results.		66
IX J-20	Dieldrin	I	S	19 ppb	15 mg/g carbon capacity for a final conc. of 0.05 ppb.		38

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX J-21	Dieldrin	L,B,I	P	19 ppb	15 mg/g carbon capacity for a final conc. of 0.08 ppb.	Pulverized FS-300	8
IX J-22	Dieldrin	C,P	H	11 ppb @ 0.1MG treated	No detectable level in effluent w/17 min contact time.	Treated by EPA mobile trailer.	6
IX J-23	Dieldrin	C,P	H	60.5ppb @ 3000 gal treated.	No detectable level in effluent w/240 min contact time.	See IXJ-22 for comments.	6
IX J-24	Dieldrin	B,L,R	P,R	10 ppb	Carbon Conc. — % Removal 5 mg/l — 75 10 mg/l — 85 20 mg/l — 92	Cumulative removal following prechlorination & coagulation-sedimentation.	6
IX J-25	Dieldrin	C,L,R	P,R	10 ppb @ 0.5 gpm/ft^3	Greater than 99% reduction achieved.	See IXJ- 24 for comments.	6
IX J-26	Dieldrin	I	I	19 ppb pH=7.0	See IXJ-10 results.		66
IX J-27	Endrin	I	I	62 ppb pH=7.0	100 mg/g carbon capacity for a final conc. of 0.05 ppb.		66
IX J-28	Endrin	L,B,I	P	62 ppb	100 mg/g carbon capacity for a final conc. of 0.07 ppb	Pulverized FS-300	8
IX J-29	Endrin	B,L,R	P,R	10 ppb	Carbon Conc. — % Removal 5 mg/l — 80 10 mg/l — 90 20 mg/l — 94	See IXJ-24 for comments.	6

(continued)

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX J-30	Endrin	C,L,R	P,R	10 ppb @ 0.5 gpm/ft^3	Greater than 99% reduction achieved.	See IXJ-24 for comments.	6
IX J-31	Endrin	I	S	62 ppb pH = 7.0	See IXJ-27 results.		38
IX J-32	Heptachlor	C,P	H	6.1 ppb @ 0.1 MG treated	99% reduction w/17 min contact time.	Treated by EPA mobile trailer.	6
IX J-33	Heptachlor	C,P	H	80 ppb @ 3000 gal treated	99.9% reduction w/240 min contact time.	Treated by EPA mobile trailer.	6
IX J-34	Herbicides (unspecified)	R	U	10,000 ppm TOC @ 0.02 MGD	99% TOC reduction achieved w/412 min contact time.	Pretreatment included pH adjustment.	38
IX J-35	Herbicides (unspecified)	R	U	1500 ppm TOC @ 0.02 MGD	90% TOC reduction achieved w/412 min contact time.	Pretreatment included settling and filtration	38
IX J-36	Kepone	C,P	H	4000 ppb @ 0.225MG treated	No detectable levels in effluent w/45 min contact time.	Treated by EPA mobile trailer.	6
IX J-37	Lindane	B,L,R	P,R	10 ppb	Carbon Conc. — % Removal 5 mg/l — 30 10 mg/l — 55 20 mg/l — 80	See IXJ-24 for comments.	6

(continued)

TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX J-38	Lindane	C,L,R	P,R	10 ppb @ 0.5 gpm/ft^3	Greater than 99% reduction achieved.	See IXJ-24 for comments.	6
IX J-39	Parathion	B,L,R	P,R	10 ppb	Carbon Conc. — % Removal 5 mg/l — >99 10 mg/l — >99 20 mg/l — >99	See IXJ-24 for comments.	6
IX J-40	Parathion	C,L,R	P,R	10 ppb	Greater than 99% reduction achieved.	See IXJ-24 for comments.	6
IX J-41	2,4,5-T ester	B,L,R	P,R	10 ppb	Carbon Conc. — % Removal 5 mg/l — 80 10 mg/l — 90 20 mg/l — 95	See IXJ-24 for comments.	6
IX J-42	2,4,5-T ester	C,L,R	P,R	10 ppb @ 0.5 gpm/ft^3	Greater than 99% reduction achieved.	See IXJ-24 for comments.	6
IX J-43	Toxaphene	C,P	P	36 ppb @ 0.25 MG treated	97% reduction w/26 min contact time.	Treated by EPA mobile trailer.	6
IX J-44	Toxaphene	L,B,I	P	155 ppb	42 mg/g carbon capacity for a final conc. of <1.0 ppb.	Pulverized FS-300.	8
IX J-45	Toxaphene	I	S	155 ppb	See IXJ-44 results.		38

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Phenols(K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX K-1	Butyl Phenol	C,P	H	300 ppb	95% reduction w/8.5 min contact time.	250,000 gal spill treated by EPA mobile treatement trailer.	6
IX K-2	4-Chloro-3-Methylphenol	B,L	P	100 ppb	100% reduction; 10% desorbed from carbon by elutriation w/solvent.	Calgon FS-300 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, chloroform-acetone and acetone.	20
IX K-3	Cresol	C,P	H	230 ppb	96.5% reduction w/8.5 min contact time.	250,000 gal spill treated by EPA mobile treatment trailer.	6
IX K-4	2,3-Dichloro phenol	B,L	P	100 ppb	100% reduction; 14% desorbed from carbon by elutriation w/solvent.	See IXK-2 for comments.	20
IX K-5	Dimethylphenol	C,P	H	1220 ppb	99.6% reduction w/8.5 min contact time.	See IXK-3 for comments.	6
IX K-6	3,5-Dimethyl phenol	B,L	P	100 ppb	100% reduction; 5% desorbed from carbon by elutriation w/solvent.	See IXK-2 for comments.	20
IX K-7	2,4-Dinitrophenol	I	P		For pH=3.0: Carbon capacity=405mg/g K =168 1/n =0.38 r =0.99		21

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Phenols(K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX K-7 cont					For pH=7.0: Carbon capacity=160mg/g K =18 1/n =0.95 r =0.94 For pH=9.0: Carbon capacity=75 mg/g K =41 1/n =0.25 r =0.87		
IX K-8	Nonylphenol	I	P		For pH=3.0: Carbon capacity=570mg/g K =55 1/n =1.03 r =0.97 For pH=7.0: Carbon capacity=595mg/g K =254 1/n =0.37 r =0.98 For pH=9.0: Carbon capacity=275mg/g K =148 1/n =0.27 r =0.98		21
IX K-9	Pentachlorophenol	I	P		For pH=3.0: Carbon capacity=635mg/g K =260 1/n =0.4 r =0.98		21

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Phenols(K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX K-9 cont					For pH=7.0: Carbon capacity=385mg/g K =145 1/n =0.42 r =0.98 For pH=9.0: Carbon capacity=260mg/g K =100 1/n =0.41 r =0.98		
IX K-10	Pentachlorophenol	C,P	H	10 ppm	Not detectable in effluent after 26 min contact time.	215,000 gal treated by EPA mobile treatment trailer.	6
IX K-11	Phenol	B,L	P	100 ppb	100% reduction; 6% desorbed from carbon by elutriation w/solvent.	See IXK-2 for comments.	20
IX K-12	Phenol	I	P		For pH=3.0: Carbon capacity=85 mg/g K =12 1/n =0.38 r =0.92 For pH=7.0: Carbon capacity=80 mg/g K =13 1/n =0.77 r =0.91 For pH=9.0: Carbon capacity=70 mg/g K =22		21

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TABLE C-1 (continued)

Concentration Process: Activated CArbon (IX)
Chemical Classification: Phenols(K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX K-12 cont					1/n =0.49 r =0.94		
IX K-13	Phenol	I	P	1.0 ppm	Adsorption capacity 21 mg/g		21
IX K-14	Phenol	C,P	H	140 ppb	100% reduction w/8.5 min contact time.	See IXK-3 for comments.	6
IX K-15	Phenol	L,I	P	100 ppm 500 ppm 1000 ppm	99% reduction 99% reduction 99% reduction	24 hr contact time time w/carbon dose of 10x phenol conc.	72
IX K-16	Phenol	I	S	1000 ppm	80% reduction; 194 ppm final conc., 161 mg/g carbon capacity.		35
IX K-17	Phenol	R	U	200 ppm @ 0.05 MGD	Effluent conc. of 0.01 ppm achievable at contact time of 165 min.	Settling,equalization & mixed media filtration used as pretreatment.	38
IX K-18	Phenol	R	U	600 ppm @ 0.2MGD	Effluent conc. of 100ppm achievable at contact time of 41 min.	Equalization used as pretreatment.	38
IX K-19	Phenol	R	U	800 ppm @0.15MGD	Effluent con. of 0.05ppm achievable at contact time of 24 min.	Biological & mixed media filtration used as pretreatment	38
IX K-20	Phenol	R	U	1200 ppm @0.15MGD	Effluent conc. of 1.0ppm achievable at contact time of 55 min.	Sand filtration & settling used as pretreatment.	38

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IXK-21	Phenol	R	U	80 ppm @ 0.3MGD	Effluent conc. of 1.0ppm achievable at contact time of 33 min.	Biological, settling & multi media filtration used as pretreatment.	38
IXK-22	Phenol	R	U	1000 ppm	80.6% reduction achieved	500 mg/l carbon dose used.	90
IXK-23	Phenol	B,L	P	100 ppb	100% reduction; 6% desorbed from carbon by elutriation w/solvent.	See IXK-2 for comments.	20
IXK-24	Resorcinol	B,L	P	100 ppb	100% reduction; 0% desorbed from carbon by elutriation w/solvent.	See IXK-2 for comments.	20
IXK-25	2,4,6-Trichlorophenol	B,L	P	100 ppb	100% reduction; 0% desorbed from carbon by elutriation w/solvent.	See IXK-2 for comments.	20
IXK-26	Trimethylphenol	C,P	H	130 ppb	92% reduction w/8.5 min contact time.	See IXK-3 for comments.	6

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Phthalates (L)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX L-1	Bis(2-ethyl-hexyl)Phthalate	B	I	1300 ppb @ 1.0gpm/ft^2	Final conc. of <22 ppb achiev able at 90 min EBCT.	TOC conc. of influent was 15000 ppm;estimated cost excluding pretreatment was $27.00/1000 gal	5
IX L-2	Bis(2-Ethyl-hexyl)Phthalate	R	U		Reduction by flocculation w/$Al_2(SO_4)_3$ improved w/granular activated carbon pretreatment.		90
IX L-3	Dibutyl Phthalate	B,L	P	100 ppb	100% reduction; 38% desorbed from carbon by elutriation w/solvent.	Calgon FS-300 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, chloroform-acetone and acetone.	20
IX L-4	Dimethyl Phthalate	B,L	P	100 ppb	100% reduction; 13% desorbed from carbon by elutriation w/solvent.	See IXL- 3 for comments.	20

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TABLE C-1(continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Polynuclear Aromatics (M)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
IX M-1	Biphenyl	B,L	P	100 ppb	100% reduction; 2% desorbed from carbon by elutriation w/solvent.	Calgon FS-300 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, chloroform-acetone and acetone.	20
IX M-2	Cumene	B,L	P	100 ppb	100% reduction; 8% desorbed from carbon by elutriation w/solvent.	See IXM-1 for comments.	20
IX M-3	Dimethyl-Naphthalene	B,L	P	100 ppb	80% reduction; 11% desorbed from carbon by elutriation w/solvent.	See IXM-1 for comments.	20
IX M-4	1,1-Diphenyl-hydrazine	I	P	pH=7.5	Isotherm kinetics were as follows: Carbon K 1/n Darco 94.8 0.279 Filtrasorb 149.0 0.232 Carbon dose (mg/l) required to reduce 1.0 mg/l to 0.1mg/l: Darco - 18.0 Filtrasorb - 10.0		31
IX M-5	Fluoranthrene	B,L	P	100 ppb	80% reduction; 5% desorbed from carbon by elutriation w/solvent.	See IXM-1 for comments.	20
IX M-6	Napthalene	I	P		Isotherm kinetics were as follows: Carbon K 1/n Darco 62.8 0.30 Filtrasorb 1.69 0.56		31

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TABLE C-1 (continued)

Concentration Process: Activated Carbon (IX)
Chemical Classification: Polynuclear Aromatics (M)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
IX M-6 cont					Carbon dose (mg/l) required to reduce 1.0mg/l to 0.1mg/l: Darco - 29.0 Filtrasorb - 19.0		
IX M-7	Napthalene	F,C	M	Conc. not reported	70% reduction achieved in carbon treatment phase.	Carbon used as advanced treatment of biologically & chemically treated wastewater. Plant capacity 0.66 M^3/sec.	64
IX M-8	Phenanthrene	B,L	P	100 ppb	80% reduction; 6% desorbed from carbon by elutriation w/solvent.	See IXM- 1 for comments.	20
IX M-9	Pyrene	B,L	P	100 ppb	80% reduction; 5% desorbed from carbon by elutriation w/solvent.	See IXM- 1 for comments.	20

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TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XA-1	Butanol	B,L	P	100 µg/l	Complete removal. 38% desorption of butanol by elutriation with solvent was achieved.	Resin was Amberlite XAD-2. Resin found to be more effective than carbon for phthalate esters, most aromatics, and pesticides. Carbon was more efficient for alkanes; neither effective for acidic compounds.	20
XA-2	Cyclohexanol	B,L	P	100 µg/l	Complete removal. 81% desorption of cyclohexanol by elutriation with solvent was achieved.	See XA-1 for additional results.	20
XA-3	Decanol	B,L	P	100 µg/l	Complete removal. 89% desorption of decanol by elutriation with solvent was achieved.	See XA-1 for additional results.	20
XA-4	2-Ethyl-1-Hexanol	B,L	P	100 µg/l	Complete removal. 100% desorption of 2-Ethyl-1-Hexanol by elutriation with solvent was achieved.	See XA-1 for additional results.	20
XA-5	m-Heptanol	B,L	P	100 µg/l	Complete removal. 100% desorption of n-Heptanol by elutriation with solvent was achieved.	See XA-1 for additional results.	20
XA-6	Octanol	B,L	P	100 µg/l	Complete removal. Greater than 100% desorption of Octanol by elutriation with solvent was reported.	See XA-1 for additional results.	20

(continued)

TABLE C-1(continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Alcohols (A)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XA-7	Pentanol	B,L	P	100 µg/l	Complete removal. 67% desorption of pentanol by elutriation with solvent was achieved.	See XA-1 for additional results.	20
XA-8	Propanol	B,L	P	100 µg/l	Complete removal. Propanol could not be desorbed by elutriation with solvent.	See XA-1 for additional results.	20

(continued)

TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XB-1	Butyric Acid	B,L	P	100 µg/l	100% reduction; no desorption from resin by elutriation with solvent.	Resin was Amberlite XAD-2. Resin found to be more effective than carbon for phthalate esters, most aromatics, and pesticides; carbon more efficient for alkanes; neither effective for acidic compounds.	20
XB-2	Caproic Acid	B,L	P	100 µg/l	50% reduction; 6% desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-3	Decanoic Acid	B,L	P	100 µg/l	100% reduction; No desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-4	Dodecane	B,L	P	100 µg/l	25% reduction; No desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-5	Heptanoic Acid	B,L	P	100 µg/l	50% reduction; 4% desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-6	Hexadecane	B,L	P	100 µg/l	25% reduction; No desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-7	Lauric Acid	B,L	P	100 µg/l	100% reduction; No desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-8	Methyl Decanoate	B,L	P	100 µg/l	100% reduction; 50% desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20

(continued)

TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Aliphatics (B)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XB-9	Methyl Dodecanoate	B,L	P	100 µg/l	100% reduction; 72% desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-10	Methyl Hexadecanoate	B,L	P	100 µg/l	100% reduction; 67% desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-11	Methyl Octadecanoate	B,L	P	100 µg/l	100% reduction; 54% desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-12	Myristic Acid	B,L	P	100 µg/l	100% reduction; No desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-13	Octadecane	B,L	P	100 µg/l	25% reduction; No desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-14	Octanoic Acid	B,L	P	100 µg/l	90% reduction; No desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-15	Propionic Acid	B,L	P	100 µg/l	100% reduction; No desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-16	Pyruvic Acid	B,L	P	100 µg/l	100% reduction; No desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-17	Tetradecane	B,L	P	100 µg/l	50% reduction; 23% desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20
XB-18	Valeric Acid	B,L	P	100 µg/l	50% reduction; 2% desorption from resin by elutriation with solvent.	See XB-1 for additional results.	20

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TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
XC-1	Aniline	B,L	P	100 µg/l	Complete removal; No desorption from resin by elutriation with solvent.	Resin was Amberlite XAD-2. Resin found to be more effective than carbon for phthalate esters, most aromatics, and pesticides; carbon was more efficient for alkanes; neither effective for acidic compounds.	20
XC-2	Butylamine	B,L	P	100 µg/l	Complete removal; 74% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20
XC-3	Cyclohexylamine	B,L	P	100 µg/l	Complete removal; 94% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20
XC-4	Dibutylamine	B,L	P	100 µg/l	Complete removal; 62% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20
XC-5	Dihexylamine	B,L	P	100 µg/l	Complete removal; 11% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20
XC-6	Dimethylamine	B,L	P	100 µg/l	100% removal; 50% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20
XC-7	Hexylamine	B,L	P	100 µg/l	100% removal; 110% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20

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TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Amines (C)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XC-8	Morpholine	B,L	P	100 µg/l	100% removal; 28% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20
XC-9	Octylamine	B,L	P	100 µg/l	100% removal; 15% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20
XC-10	Piperidine	B,L	P	100 µg/l	100% removal; 42% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20
XC-11	Pyrrole	B,L	P	100 µg/l	100% removal; 5% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20
XC-12	Tributylamine	B,L	P	100 µg/l	100% removal; 108% desorption from resin by elutriation with solvent.	See XC-1 for additional results.	20

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TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XD-1	Acetophenone	B,L	P	100 µg/1	100% reduction; 80% desorption from resin by elutriation with solvent.	Resin was Amberlite XAD-2. Resin found to be more effective than carbon for phthalate esters, most aromatics, and pesticides; carbon more efficient for alkanes; neither effective for acid compounds.	20
XD-2	Benzaldehyde	B,L	P	100 µg/1	100% reduction; 79% desorption from resin by elutriation with solvent.	See XD-1 for additional results.	20
XD-3	Benzil	B,L	P	100 µg/1	100% reduction; 63% desorption from resin by elutriation with solvent.	See XD-1 for additional results.	20
XD-4	Benzoic Acid	B,L	P	100 µg/1	100% reduction; No desorption from resin by elutriation with solvent.	See XD-1 for additional results.	20
XD-5	Benzene, Toluene, Xylene (BTX)	P	I	20 to 300 ppm	Effluent (leakage) is 0.2ppm	Costs estimated to be $3.36/1000 gal. at 250 gpm and 300 ppm BTX. Resin regenerant is steam. Recovery of BTX reduces costs to $1.09/1000 gal.	32
XD-6	Cumene	B,L	P	100 µg/1	100% removal; 63% desorption from resin by elutriation with solvent.	See XD-1 for additional results.	20

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TABLE C-1(continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
XD-7	m-Dichlorobenzene	B,L	P	100 µg/l	100% removal; 52% desorption from resin by elutriation with solvent.	See XD-1 for additional results.	20
XD-8	o-Dichlorobenzene	B,L	P	100 µg/l	100% removal; 61% desorption from resin by elutriation with solvent.	See XD-1 for additional results.	20
XD-9	p-Dichlorobenzene	B,L	P	100 µg/l	100% removal; 35% desorption from resin by elutriation with solvent.	See XD-1 for additional results.	20
XD-10	1,2,4-Trichlorobenzene	B,L	P	100 µg/l	100% removal; 67% desorption from resin by elutriation with solvent.	See XD-1 for additional results.	20
XD-11	2,4,6-Trinitrotoluene (TNT)	P,C	I	81 to 116 ppm	Resin adsorption capacity was 0.116 to 0.154 gm/gm at 1 ppm breakthrough. No loss in capacity after 15 regeneration cycles. 1 ppm breakthrough occurred after 633 to 1193 B.V.	Amberlite XAD-4 used; acetone regenerant. Less costly than carbon due to regenerability.	2
XD-12	2,4,6-Trinitrotoluene (TNT) and other munitions plant wastewaters: Cyclonite(RDX), Nitramine (Tetryl) and cyclotetramethylene tetranitramine (HMX).	R	I	Not reported	Adsorption capacities (Lb/Lb Amberlite XAD-4 resin): Contaminant — Breakthrough — Saturation TNT — 0.020 — 0.050 RDX — 0.236 — 0.382 RDX & TETRYL — 0.003 / 0.001 — 0.019 / 0.006 TNT & RDX — 0.116 / 0.020 — 0.278 / 0.030 TNT & HMX — 0.002 — 0.179	For 80 gpm facility costs estimated to be $5.08/1000 gal.	40

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TABLE C-1(continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Aromatics (D)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XD-12 cont.					(Note: breakthrough conc. not defined.) Typical conc. of contaminants in wastewaters: TNT - 0-400 ppm RDX - 50-100 ppm pH - 3.5-7.0 Flow - 0.02-1.0 MGD Temp - 60-160°F		

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TABLE C-1(continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XF-1	Bromoform	L	W	0.2 ppb		See XF-16 for results.	46
XF-2	Bromoform	B,L	P	100 ppb	100% removal; 28% desorption from resin by elutriation w/solvent.	Amberlite XAD-2 used Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, methyl chloride-acetone, and acetone.	20
XF-3	Bromodichloromethane	L	W		At 2 ppm, equilibrium capacity was 48 mg/g.	See XF-16 for results.	46
XF-4	Carbon Tetrachloride	P	I	100 to 7000 ppm chlorinated hydrocarbons	Effluent of <1ppm total chlorinated hydrocarbons could be achieved.	Steam used as regenerant. Costs estimated to be $1.18/1000 gal at 250 gpm & 300 ppm influent conc., $2.52/1000 gal at 60 gpm & 500 ppm, and $3.36/1000 gal at 60 gpm & 7500 ppm.	32
XF-5	Chloroform	P	I	100 to 7000 ppm chlorinated hydrocarbons	Effluent of <1ppm total chlorinated hydrocarbons could be achieved.	See XF-4 for comments.	32
XF-6	Chloroform	L	W	1.1 ppb	At 2ppm, equilibrium capacity was 50 mg/g.	See XF-16 for results.	46

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TABLE C-1(continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XF-7	Dibromochloromethane	L	W	3.9 ppb		See XF-16 for results.	46
XF-8	1,1-Dichloroethane	L	W	2.3 ppb		See XF-16 for results.	46
XF-9	1,2-Dichloroethane	L	W	2.1 ppb		See XF-16 for results.	46
XF-10	1,2-Dichloroethylene	L	W	0.2 ppb		See XF-16 for results.	46
XF-11	Ethylene Dichloride	P	I	100 to 7000 ppm chlorinated hydrocarbons	Effluent of <1ppm total chlorinated hydrocarbons could be achieved.	See XF-4 for comments.	32
XF-12	Hexachlorobutadiene	B,L	P	100 ppb	100% removal; 73% desorption from resin by elutriation with solvent	See XF-2 for comments.	20
XF-13	Hexachloroethane	B,L	P	100 ppb	100% removal; 55% desorption from resin by elutriation with solvent	See XF-2 for comments.	20
XF-14	Tetrachloroethane	B,L	P	100 ppb	100% removal; 53% desorption from resin by elutriation with solvent	See XF-2 for comments.	20
XF-15	Tetrachloroethylene	L	W	179 ppb		See XF-16 for results.	46
XF-16	1,1,1-Trichloroethane	L	W	551 ppb	Performance for treatment of water containing several halogens	Column studies: 14 mm dia glass tubes, height 4" (15 cu cm adsorbent)	46

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TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Halocarbons (F)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XF-16 cont					Virgin / Regenerated BV to 33 ppb compound leakage: 9000 / 8500 Days: 23.4 / 22.1 Gal treated/cu ft sorbent: 67500 / 63750	Flow-2 gpm/cu ft (16 BV/hr) Regenerated at 37 lb steam/cu ft @ 5 psig	
XF-17	1,2,3-Trichloropropane	B,L	P	100 ppb	Complete removal w/complete desorption by elutriation w/solvent.	See XF-2 for comments.	20

(continued)

TABLE C-1(continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Polychlorinated Biphenyls (I)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XI-1	Arochlor 1254	B,L	P	100 ppb	100% reduction; 76.6% desorbed from carbon by elutriation w/solvent.	Amberlite XAD-2 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, chloroform-acetone & acetone.	20
XI-2	Arochlor 1254	C,L	P	0-25 ppb 100ml/hr	Final effluent conc. was 0-0.25 ppb for 192 B.V.	5 day study.	22
XI-3	Arochlor 1254 & 1260	C	M	1-25 ppb	60% reduction w/Amberlite XAD-4. 23% ± 2% reduction w/Amberlite XAD-2.	In continuous flow system reduction decreased greatly w/time.	57

(continued)

TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XJ-1	Aldrin	B,L	P	100 ppb	100% reduction; 39% desorbed from resin by elutriation w/solvent.	Amberlite XAD-2 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, chloroform-acetone and acetone	20
XJ-2	Atrazine	B,L	P	100 ppb	100% reduction; 38% desorbed from resin by elutriation w/solvent.	See XJ-1 for comments.	20
XJ-3	Chlorinated Pesticides (Unspecified)	L	I	33 to 118 ppm	Column studies indicatd that Amberlite XAD-4 could process about four times more throughput before experiencing some leakage as carbon column. Leakages of <1 ppm maintained at longer than 120 BV. Resin could be effectively regenerated w/2 BV of isopropanol whereas even 8 BV did not effectively generate carbon.	Solvents ranking in terms of decreasing effectiveness were acetone, isopropanol, and methanol; however, acetone is very flammable. Column study conditions: 50-150 BV passed, 4 BV/hr flow, 12.5-125 hr duration. Costs estimated to be $0.83 for resin sorption and $1.33/1000 gal for carbon.	49
XJ-4	2,4-D Butyl ester	B,L	P	100 ppb	100% reduction; 10% desorbed from resin by elutriation w/solvent.	See XJ-1 for comments.	20
XJ-5	2,4-D and related herbicides	U	I	20-1500 ppm @70-80 gpm	Effluent conc. reduced to <1.0 ppm.	Amberlite XAD-4 resin used.	20

(continued)

TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Pesticides (J)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XJ-6	DDT	B,L	P	100 ppb	100% reduction; 49% desorbed from resin by elutriation w/solvent.	See XJ-1 for comments.	20
XJ-7	Endrin and Heptachlor	F	I	0.1-2.0 ppm @ 100 gpm	Effluent conc. reduced to <3.0 ppb.	Amberlite XAD-4 used.	32
XJ-8	Toxaphene	U	I	70-2600 ppb	Effluent conc. reduced to 0.1-4.2 ppb.	Amberlite XAD-4 used.	32

(continued)

TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study Study Type[c]	 Waste Type[d]	 Influent Char.	Results of Study	Comments	Ref.
XK-1	Bisphenol-A	C,L	I	900 ppm 2 BV/hr	At pH 11.4, poor adsorption achieved on either XAD-4 or XAD-7. At pH 10.0, XAD-4 treated 33.5 B.V.'s to 50ppm breakthrough. XAD-7 treated 16 B.V. to 50 ppm breakthrough.	95% regeneration achieved w/1 B.V. of 4% NaOH & 4 B.V. deionized water.	23
XK-2	Bisphenol-A	C,L	I	280 ppm 2 BV/hr	At pH 6.9, XAD-4 capacity was 34 g/l and XAD-7 capacity was 16 g/l.	See XK-1 for comments.	23
XK-3	Brine Phenol	U	I	20% brine w/10-150 ppm phenol	Effluent conc. reduced to <0.5 ppm.	Wastewater of brine purification process 5 B.V. of 4% NaOH required for regeneration	33
XK-4	Brine Phenol	U	I	10% brine w/10-400 ppm phenol	Effluent conc. reduced to <2.0 ppm phenols using cross linked polystyrene macroreticular resin.	Wastewater from a phenoxy acid pesticide manufacturer.	33
XK-5	4-Chloro-3-methylphenol	B,L	P	100 ppb	100% reduction; 70% desorbed from resin by elutriation w/solvent.	Amberlite XAD-2 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, chloroform-acetone and acetone.	20
XK-6	m-Chlorophenol w/13% NaCl	U	I	350 ppm @ 0.5 gpm/ft^3	At zero leakage sorption capacity was 0.07 lb/lb.	15 min contact time Amberlite XAD-4 used.	66

(continued)

TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XK-7	2,4-Dibromophenol	B,L	P	100 ppb	100% reduction; 44% desorbed from resin by elutriation w/solvent.	See XK-5 for comments.	20
XK-8	Dichlorophenol	U	I	1500 ppm w/15% brine, pH = 2-3	Resin capacity was 5.6 lb phenols/ft^3 @ 5 ppm breakthrough.	Amberlite XAD-2 used. 2% caustic soda heated to 80^0-85^{0}C used as regenerant.	33
XK-9	2,3-Dichlorophenol	B,L	P	100 ppb	100% reduction; 54% desorbed from resin by elutriation w/solvent.	See XK-5 for comments.	20
XK-10	2,4-Dichlorophenol	U	I	430 ppm @ 0.5 gpm/ft^3	At zero leakage sorption capacity was 0.116 lb/lb.	15 min contact time. Amberlite XAD-4 used.	66
XK-11	β-Napthol	B,L	P	100 ppb	100% reduction; 76% desorbed by elutriation w/solvent.	See XK-5 for comments.	20
XK-12	p-Nitrophenol	C,L	I	700-1300 ppm @ 50^{0}C	Effluent conc. reduced to 5.0-6.0 ppm for 32 B.V. Resin capacity was about 40 g/l. Efficient ethanol regeneration.	Amberlite XAD-7 used. 20 ml columns used w/experimental runs of up to 40 B.V.	23
XK-13	p-Nitrophenol	U	I	1000-1800 ppm @ pH=2.0	Effluent conc. reduced to 1-5 ppm by cross-linked polystyrene adsorbent resin.	Effluent from parathion manufacturer. 4% aqueous caustic soda (2B.V.) followed by water rinse used as regnerant.	33
XK-14	Pentachlorophenol	B,L	P	100 ppb	100% reduction; 60% desorbed from resin by elutriation w/solvent.	See XK-5 for comments.	20

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TABLE C-1 (continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Phenols (K)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XK-15	Phenol	C,L	P	6700 ppm	Effluent conc. of <1.0 ppm achieved.	Amberlite XAD-4 used. Acetone & methanol used as regenerants.	23
XK-16	Phenol	U	I	500-1500 ppm	Effluent conc. of 1.0-3.0ppm achieved.	Amberlite XAD-4 used. Wastewater from Bisphenol A manufacturer containing 0.5-1.5% phenol, 0.5-1.0% NaCl, 100-1000 ppm acetone @ pH=0.2-1.5. Acetone & methanol used as regenerant.	33
XK-17	Phenol	U	I	5000 ppm	Effluent conc. reduced to <25 ppm.	Wastewater from phenolic resin manufacturer. Warm 44% formaldehyde used as regenerant.	33
XK-18	Resorcinol	B,L	P	100 ppb	100% reduction;35% desorbed from resin by elutriation w/solvent.	See XK-5 for comments.	20
XK-19	2,4,6-Trichlorophenol	B,L	P	100 ppb	100% reduction; 60% desorbed from resin by elutriation w/solvent.	See XK-5 for comments.	20
XK-20	2,4,6-Trichlorophenol	U	I	510 ppm @ 0.5 gpm/ft^3	At zero leakage sorption capacity was 0.272 lb/lb.	15 min contact time. Amberlite XAD-4 used.	66

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TABLE C-1(continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Phthalates (L)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XL-1	Dibutyl Phthalate	B,L	P	100 ppb	100% reduction; 108% desorbed from resin by elutriation w/solvent.	Amberlite XAD-2 used. Solvents included pentane-acetone, diethylether, methylene chloride-acetone, chloroform-acetone & acetone.	20
XL-2	Diethylhexyl Phthalate	B,L	P	100 ppb	100% reduction; 76% desorbed from resin by elutriation w/solvent.	See XL-1 for comments.	20
XL-3	Dimethyl Phthalate	B,L	P	100 ppb	100% reduction; 62% desorbed from resin by elutriation w/solvent.	See XL-1 for comments.	20

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TABLE C-1(continued)

Concentration Process: Resin Adsorption (X)
Chemical Classification: Polynuclear Aromatics (M)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XM-1	Acenapththalene	B,L	P	100 ppb	100% reduction; 78% desorbed from resin by elutriation w/solvent.	Amberlite XAD-2 used. Solvents included pentane-acetone, diethyl ether, methylene chloride-acetone, chloroform-acetone & acetone.	20
XM-2	Biphenyl	B,L	P	100 ppb	100% reduction; 73% desorbed from resin by elutriation w/solvent.	See XM- 1 for comments.	20
XM-3	Cumene	B,L	P	100 ppb	100% reduction; 63% desorbed from resin by elutriation w/solvent.	See XM- 1 for comments.	20
XM-4	Dimethyl-naphthalene	B,L	P	100 ppb	100% reduction; 90% desorbed from resin by elutriation w/solvent.	See XM-1 for comments.	20
XM-5	Fluoranthrene	B,L	P	100 ppb	100% reduction; 66% desorbed from resin by elutriation w/solvent.	See XM-1 for comments.	20
XM-6	Phenanthrene	B,L	P	100 ppb	100% reduction; 41% desorbed from resin by elutriation w/solvent.	See XM-1 for comments.	20
XM 7	Pyrene	B,L	P	100 ppb	100% reduction; 63% desorbed from resin by elutriation w/solvent.	See XM-1 for comments.	20

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TABLE (continued)

Concentration Process: Miscellaneous Sorbents (XII)
Chemical Classification: Metals (G)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XII G-1	Arsenic	R	U	25 ppm	Effluent conc. of 1.0ppm achieved.	Silicon alloy used.	90
XII G-2	Cadmium	R	U	25 ppm	Effluent conc. of 1.0ppm achieved.	Silicon alloy used.	90
XII G-3	Chromium	R	U	300 ppm	100% removal.	High clay soil used.	90
XII G-4	Copper	R	U	300 ppm	100% removal.	High clay soil used.	90
XII G-5	Copper	R	U	25 ppm	Effluent conc. of 1.0ppm achieved.	Silicon alloy used.	90
XII G-6	Lead	R	U		Residual of <5.0 mg/l achieved.	Ground redwood bark used.	90
XII G-7	Lead	R	U	25 ppm	Effluent conc. of 1.0ppm achieved.	Silicon alloy used.	90
XII G-8	Mercury	R	U	25 ppm	Final conc. of 10 ppb achieved.	Silicon alloy used.	90
XII G-9	Zinc	R	U	10 ppm	Final conc. reduced to 0.1 ppb.	SiO_2 & CaO slags used.	90

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TABLE C-1(continued)

Sorbents

Concentration Process: Miscellaneous Sorbents (XII)
Chemical Classification: Polychlorinated Biphenyls (I)

No.[a]	Chemical[b]	Description of Study			Results of Study	Comments	Ref.
		Study Type[c]	Waste Type[d]	Influent Char.			
XII I-1	Arochlor 1254 & 1260	C	M	1-25 ppb	73% reduction in raw sewage w/PVC chips. Polyurethane foam adsorbed 35% ± 3%.	In continuous flow system reduction decreased greatly w/time.	57

Footnotes:

a. Three part code number assigned to each individual chemical compound. First part is a Roman numeral which corresponds to the concentration process code number. Second part is a capital letter corresponding to the chemical classification code number. Third part is unique number for each individual compound.

b. Chemicals are presented in alphabetical order generally according to The Merck Index preferred or generic name. However, it is recommended to check for a compound under several potential names.

c. Describes the scale of the referenced study:

B - Batch Flow
C - Continuous Glow
F - Full Scale
I - Isotherm Test
L - Laboratory Scale
N - Flow Not Controlled

O - Respirometer Study
P - Pilot Scale
R - Literature Review
S - Slug Dose Chemical Addition
U - Unknown

(continued)

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Footnotes (continued):

d. Describes the type of wastewater used in the referenced study:

D - Domestic wastewater
H - Hazardous material spill
I - Industrial wastewater
P - Pure Compound (one solute in a solvent)
R - River water
S - Synthetic wastewater
U - Unknown
W - Well water